BMP Planning to Address Urban Runoff

Beauty Creek Watershed Pilot

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Prepared for

U.S. Environmental Protection Agency -- Region 5
Indiana Department of Environmental Management
Save the Dunes

Prepared by

Tetra Tech, Inc.
1468 West Ninth Street, Suite 620
Cleveland, OH 44113

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Acronyms and Abbreviations

BMP	best management practice
CSO	combined sewer overflow
DEM	digital elevation model
GLRI	Great Lakes Restoration Initiative
HRU	hydrologic response unit
HSPF	Hydrologic Simulation Program FORTRAN
HUC	hydrologic unit code
IBC	impaired biotic communities
IDEM	Indiana Department of Environmental Management
LID	low impact development
LSPC	Loading Simulation Program C++
MS4	municipal separate storm sewer system
NLCD	National Land Cover Dataset
PES	Payment for Ecosystem Services
SWMM	Stormwater Management Model
SUSTAIN	System for Urban Stormwater Treatment and Analysis INtegration
TMDL	total maximum daily load
TSS	total suspended solids
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey (U.S. Department of the Interior)
WMP	watershed management plan
WQv	water quality volume

Executive Summary

As part of the Great Lakes Restoration Initiative (GLRI), work is underway to strategically pilot implementation of the System for Urban Stormwater Treatment and Analysis INtegration (*SUSTAIN*) in several Great Lakes area watersheds. Problems resulting from stormwater runoff associated with urban development throughout the basin touch on each of the five focus areas of the GLRI. Many metropolitan areas in the Great Lakes region have waterbodies that are impaired due to stormwater sources, while thirty toxic hotspot Areas of Concern are still in need of cleanup. Because *SUSTAIN* identifies cost-effective methods to address problems caused by urban stormwater, the use of this tool is an essential part of the restoration plan.

This *SUSTAIN* project examined the applicability of the tool in three Great Lakes pilot watersheds: the Chagrin River watershed in Ohio; the Salt Creek watershed in northwest Indiana; and the Amity Creek watershed near Duluth, Minnesota. The project is designed to identify recommendations for Best Management Practices (BMPs) on new development and to apply *SUSTAIN* as a tool to prioritize retrofit opportunities. This includes the use of green infrastructure in combined sewer overflow (CSO) areas. In addition, these pilots serve as an opportunity to explore the use of *SUSTAIN* for determining stormwater utility credits. Results are expected to augment current efforts in promoting low impact development (LID) in these watersheds, support Watershed Action Plan and total maximum daily load (TMDL) implementation, and inform development of multiple separate storm sewer system (MS4) permits. Based on the pilot applications, these case studies provide a template for future *SUSTAIN* applications in the region.

This technical report describes work conducted for the Salt Creek watershed pilot. Building on information in the Salt Creek Watershed Management Plan (WMP), a priority management area (Beauty Creek) was selected for testing of *SUSTAIN*. The approach used in this pilot effort employed a multi-scale analysis coupled with use of a five-step process to guide application of the tool. Characterization data from development of the Salt Creek WMP and information on BMPs that have been implemented in the area were examined with *SUSTAIN*. Study results are presented in this document.

1. Introduction

Salt Creek is an important resource that provides recreational opportunities to the local residents of northwest Indiana. Situated in the Lake Michigan watershed with portions protected by the Indiana Dunes National Lakeshore, it is threatened by problems from stormwater runoff and erosion. The mainstem of Salt Creek is designated as a salmonid stream and is stocked for steelhead, coho, and chinook salmon. A TMDL was recently developed to address section 303(d) listings due to impaired biotic communities and *E. coli* bacteria.

Local concerns over water quality prompted development of the Salt Creek WMP in 2008 to address the sources of pollution to and impairments of Salt Creek. Development of the Salt Creek WMP, coordinated by Save the Dunes, was a community-driven process involving a diverse group of local citizens, experts, organizations and community leaders.

The Salt Creek WMP includes goals to reduce pollutant loads and improve biotic communities, as well as to increase stakeholder and public involvement. To achieve these goals, the Salt Creek Watershed Workgroup established three management areas (i.e., critical, priority, and intermediate) based upon historic and current water quality data, confirmed sources, projected future development, and causes of impairment. Critical management areas are considered critical for implementation of practices to improve water quality. Priority management areas are crucial for the long-term health of Salt Creek. These management areas require protective measures to maintain and enhance existing water quality. Intermediate management areas are addressed by on-going efforts under the Lake Michigan Coastal Nonpoint Source Management Program.

The Salt Creek WMP identifies activities, responsibilities, partners, potential funding sources, and general timeframes for meeting its goals. In the years following approval of the Salt Creek WMP, significant progress has been made by Save the Dunes and partner organizations on implementing the activities listed in the plan. However, work remains, particularly in the area of stormwater management to ensure the effective use of limited resources.

In 2010, Save the Dunes began working with the Indiana Department of Environmental Management (IDEM) and the U.S. Environmental Protection Agency (USEPA) Region 5 to maximize opportunities to integrate TMDL, wetland, stormwater management, low impact development, and section 319 nonpoint source management efforts on a watershed basis. One component of that effort is to test *SUSTAIN*.

The purpose of the *SUSTAIN* pilot application for Beauty Creek is to provide technical support for local planning and water quality implementation by:

- Selecting cost-effective best management practices (BMPs) that will help to address existing stormwater problems in the Salt to Creek watershed.
- Developing optimal reduction strategies for runoff volume and peak flow for the Salt Creek priority management areas (Beauty Creek).

2. Approach

Development of effective stormwater management strategies is an important part of the transition from water quality program planning to implementation. The goal of this project is to provide technical support for local stormwater planning and implementation efforts by analyzing and selecting the most appropriate suite of BMPs to achieve targeted flow volume and pollutant load reductions.

The general approach used to develop this pilot effort considers two aspects related to watershed planning and implementation. The first aspect is a framework to address the scale issues associated with watershed management. Project partners used a multi-scale analysis to examine problems caused by excess stormwater volumes and peak flows at the watershed level, building on information in the Salt Creek WMP. The multi-scale analysis moves to progressively smaller levels based on priority concerns and implementation opportunities.

The second aspect of the general approach is the use of a five-step process to identify optimal BMPs for the Salt Creek watershed. The five-step process was conducted in tandem with the multi-scale analysis; the five steps are: (1) establishing baseline conditions; (2) identifying potential BMPs; (3) evaluating opportunities and constraints; (4) estimating costs; and (5) building a stormwater management strategy.

2.1 Multi-scale Analysis

Scale of analysis is an important facet of stormwater management. The assessment can be performed at any scale. At the broadest scales (e.g., citywide), analyses of stormwater problems provide the context for policy formulation, laws, regulations, codes, and ordinances. At the finest scales (e.g., specific streets, residential lots), technical analyses provide the basis for project implementation and can be used to evaluate site-specific impacts. Mid-scale analyses (e.g., watershed level) provide the context for management through the description and understanding of typical stormwater problems and the capabilities that exist to address those problems.

Stormwater management often occurs in the mid-scale range, which allows for broad pattern recognition and process identification that in turn sets priorities for subsequent analysis. Information at this scale is typically used to guide decisions facing MS4 jurisdictions. For example, an examination of water quality issues within a small urban watershed (e.g., 1,000 acres) might illustrate that a priority problem is stream channel instability caused by unnaturally high peak flows associated with new development. Controlling peak flow can therefore be established as a high priority for the stormwater program.

Mid-scale analysis, however, does not work well for certain aspects of stormwater planning and implementation. For example, a watershed manager might not know if it is more effective to reduce peak flows through retrofitting existing detention ponds, or promoting distributed BMPs such as residential rain gardens. Furthermore, differences in the design of different BMPs can have a big impact on their performance. Analyses at a site level are better able to assess the potential effects of specific management activities, because specific BMPs and design criteria for those BMPs can be evaluated.

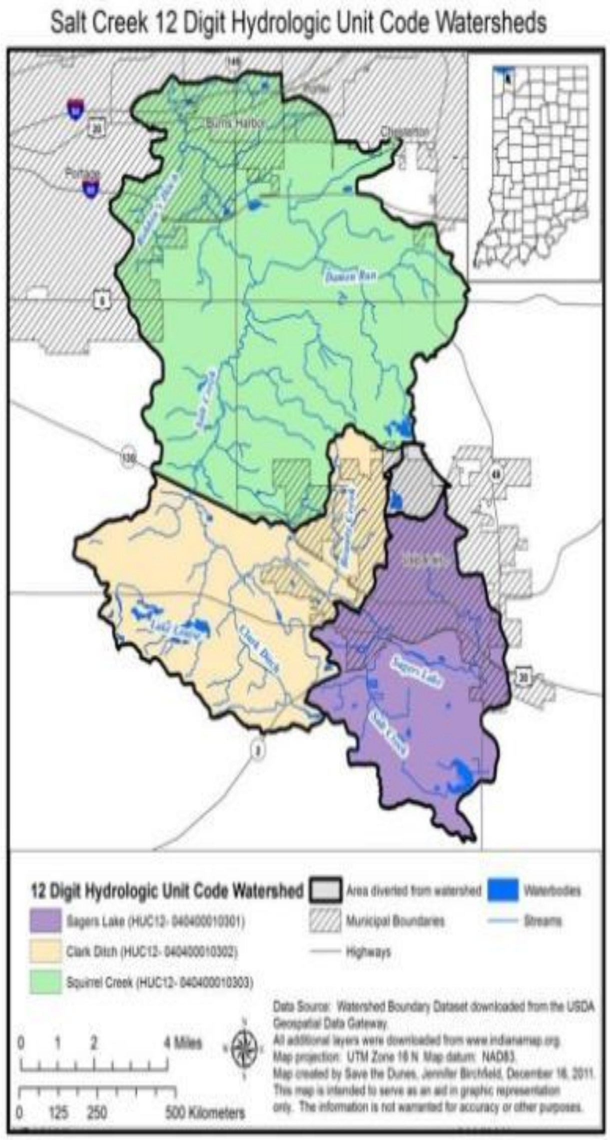


Figure 2-1. Salt Creek watershed.

Regardless of the physical area selected, each level of stormwater analysis should draw context from another and work together. For example, the technical assessment used to develop the Salt Creek WMP (Figure 2-1) guides site-level project planning and decision-making by providing the overall watershed context. Key problems and watershed goals are identified in the WMP; details of implementation should be determined through analyses at finer scales. In turn, lessons learned from site level planning (e.g., identification of the most cost-effective BMPs, including their design specifications) should be fed back to the WMP to provide refined context as management of the watershed progresses.

Stormwater managers should keep in mind that simplifying or generalizing the effects of management practices may be appropriate. Sometimes very detailed simulation or testing of BMPs can be performed and the results extrapolated to a larger scale, with such studies described as nested modeling studies. A detailed evaluation of rain gardens or porous pavement, for instance, can be performed at the street-scale using modeling or monitoring. Study results can then be used to evaluate the implications of using similar practices throughout the watershed.

In larger watersheds there are additional considerations in applying results to the entire watershed, as well as accounting for physical and chemical processes that occur on a large scale (e.g., in-stream nutrient uptake, the timing and duration of storm event peak flow at the mouth of the watershed). If the upstream conditions of a watershed significantly influence the downstream portions, it might be necessary to use a watershed model to evaluate the link between upstream and downstream indicators.

With these basic principles in mind, this pilot effort uses the following level to address scale issues.

Level 1 examines water quality, flow, and general land use patterns at the watershed (10-digit hydrologic unit code [HUC]) and subwatershed (12-digit HUC) levels. Key information that affects stormwater (e.g., rainfall-runoff relationships, distribution of pollutant loads, identification of higher density development) is used to target priority areas for subsequent analyses (e.g. catchments several hundred acres in size; groups of catchments with similar land use patterns). Delineating catchments and estimating impervious cover associated with developed land use classes are important components of Level 1.

Level 1 utilizes the BMP assessment module of *SUSTAIN* to generate performance curves. These curves bracket a range of assumptions for more significant parameters (e.g., capture depth, infiltration rate) to evaluate potential BMP effectiveness. The emphasis in Level 1 is on practices that could be applied in priority catchments, which will lead to achieving reduction targets for stormwater volume, peak flow, and pollutant loads. Level 1 can also be used to evaluate key factors affecting BMP performance. The example shown in Figure 2-2 illustrates the use of performance curves to examine the effect of different background infiltration rate assumptions on BMP performance.

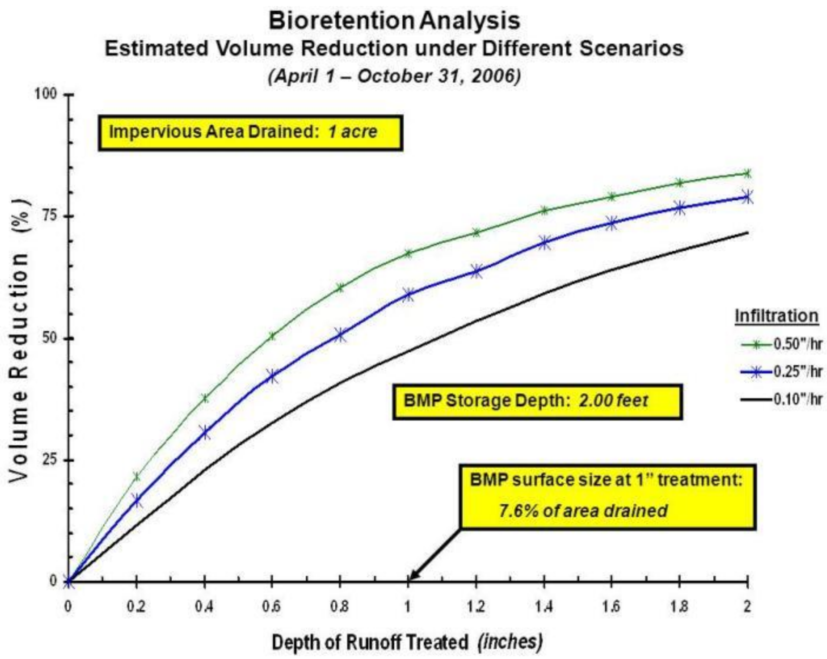


Figure 2-2. General BMP performance curve -- bioretention.

This figure demonstrates that the assumption for background infiltration rate has a relatively large effect on the predicted volume reduction and is therefore an important *SUSTAIN* input variable. Performance curves generated under Level 1 can be used to target areas within priority catchments where the use of certain BMPs might be encouraged (e.g., financial incentives offered through stormwater utility credits). In summary, the focus of Level 1 is to target priority areas for subsequent analyses and to highlight the sensitivity of key factors to be considered in identifying implementation opportunities or constraints that could prohibit the use of certain BMPs.

Level 2 moves to a smaller scale by further examining the mix of development and impervious cover present in priority catchments. This information enables the Level 2 analysis to develop estimates of volumes produced by various source areas (e.g., commercial parking, roads, residential roofs). Figure 2-3 shows an example Level 2 schematic that serves as an organizational tool for determining where certain categories of BMPs could actually be implemented (e.g., pervious pavement for parking, streets, and driveways; rain barrels coupled with rain gardens for residential roofs).

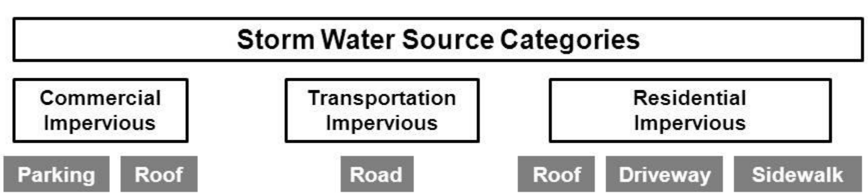


Figure 2-3. Stormwater source area types associated with Level 2 impervious cover analysis.

Because Level 2 is aimed at the catchment scale, the information on impervious cover type is more detailed. Example inventory data at this level includes: size of parking lots, street lengths and widths, number of homes, average driveway size, average roof size, sidewalk presence and size. Prioritizing the impervious areas for treatment is also a component of Level 2. Pervious space is also inventoried; both for its contribution to runoff and for consideration of potential BMPs that could be incorporated into implementation planning.

Level 2 catchment inventories enable development of estimates that describe the maximum extent to which BMPs could be applied to each impervious surface type. In addition to assessing individual practices, Level 2 factors in the potential use of treatment trains (e.g., rain barrels followed by rain gardens, flow from porous pavement systems to bioswales). The Level 2 analysis utilizes the BMP assessment module of *SUSTAIN* to develop curves that describe reductions associated with different management strategies (basically, level of implementation curves).

Level 3 draws information from Levels 1 and 2 to expand the analysis to include costs. A Level 3 evaluation uses the cost and optimization features of *SUSTAIN* to develop trade-off curves, such as the one shown in Figure 2-4. Each of the hundreds of circles within this curve represents a separate modeling run scenario with different assumptions for the number, type, and characteristics of BMPs. This type of analysis is best applied at the neighborhood (200 to 500 acre) scale because it allows for a detailed assessment of the potential BMPs and their design specifications. The model simulates the ability of each of the practices individually, and in combination, to reduce peak stream flows, taking into account the site-specific characteristics of the project area. Calculations are made at an hourly scale over a multi-year period to provide a full assessment of the response to each individual storm. At the same time, *SUSTAIN* assigns a locally-derived cost to each practice to achieve a total cost for each scenario. Plotting the combination of effectiveness and total cost for each of the hundreds of model runs results in the graph shown in Figure 2-4. The set of solutions at the far left and far top creates a cost-effectiveness curve.

Figure 2-4. Example *SUSTAIN* trade-off curve.

2.1.1 Salt Creek Watershed

The Salt Creek watershed, located in Porter County, begins in the primarily agricultural lands south of the City of Valparaiso. It flows north and west through Valparaiso and unincorporated Porter County before joining the Little Calumet River in the City of Portage (Figure 2-5). The watershed includes agricultural, forest, grassland, residential, commercial, industrial, and recreational land uses. Areas outside of the city limits are primarily agricultural, forested, and residential. Incorporated areas include most of the City of Valparaiso, the southeastern portion of the City of Portage, the southern portion of the Town of Burns Harbor, and small portions of the Towns of Chesterton and Porter.

Situated in the Lake Michigan basin with portions protected by the Indiana Dunes National Lakeshore, the Salt Creek watershed is threatened by problems from stormwater runoff and erosion. The mainstem of Salt Creek is designated as a salmonid stream; stocked for steelhead, coho, and chinook salmon. Salt Creek is on Indiana's section 303(d) list as a result of excessive *E. coli* concentrations and impaired biotic communities (IBC) (Figure 2-5). Parameters contributing to IBC include total suspended solids (TSS), total nitrogen, and total phosphorus.

A major concern throughout the Salt Creek watershed is the effect of sediment and siltation on aquatic life. Water quality data collected by Save the Dunes, IDEM's Assessment Branch, and the City of Valparaiso indicate that the greatest loads occur during high flow conditions and are generally associated with storm events. Figure 2-6 shows a load duration curve for TSS in Salt Creek using IDEM ambient water quality monitoring data collected at State Route 130. These elevated sediment loads result from surface erosion during rain events, as well as from channel incision and bank erosion in tributary streams. One example is shown in Figure 2-7, where increased stormwater volumes have led to channel instability and bank erosion on the East Branch of Beauty Creek.

In 2006, Save the Dunes began coordinating the development of a watershed management plan for Salt Creek through a section 319 grant from IDEM. The *Salt Creek Watershed Management Plan* (Save the Dunes 2008), identified three categories of management areas within the drainage: critical, priority, and intermediate (Figure 2-8). Critical management areas are considered critical for implementation of practices to improve water quality. Priority management areas are crucial for the long-term environmental health of Salt Creek and require protective measures to maintain and/or enhance existing, relatively good water quality.

Beauty Creek was designated as a priority management area in the 2008 Salt Creek WMP. Despite the relatively good water quality, biological communities in Beauty Creek were among the worst of all sites assessed. Additionally, severe erosion along Beauty Creek was noted by concerned stakeholders, as evidenced in Figure 2-7. Because it is a priority management area and because of the effects of stormwater in the drainage, Beauty Creek is the focus of this *SUSTAIN* pilot effort.

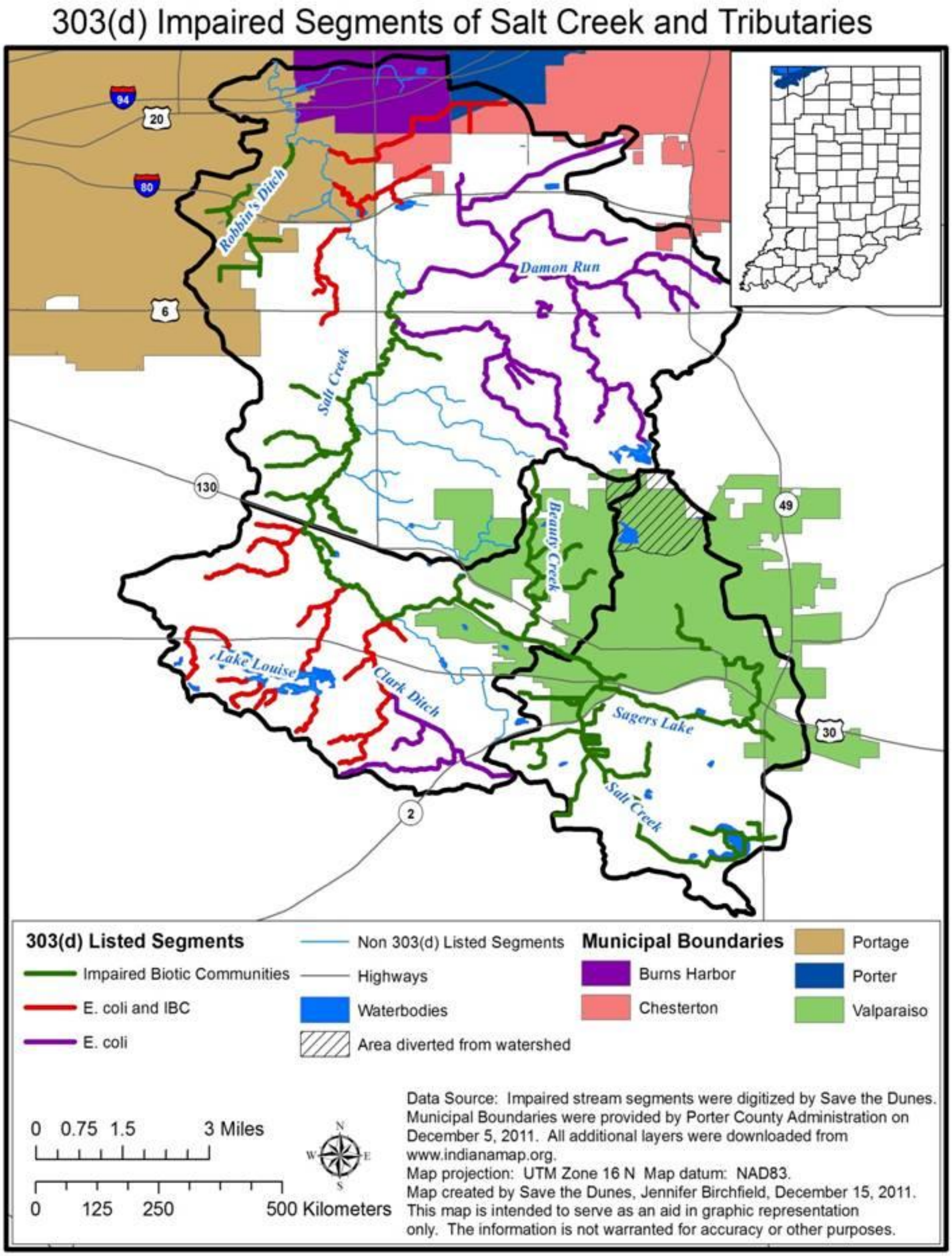


Figure 2-5. Salt Creek watershed and 303(d) impaired stream segments.

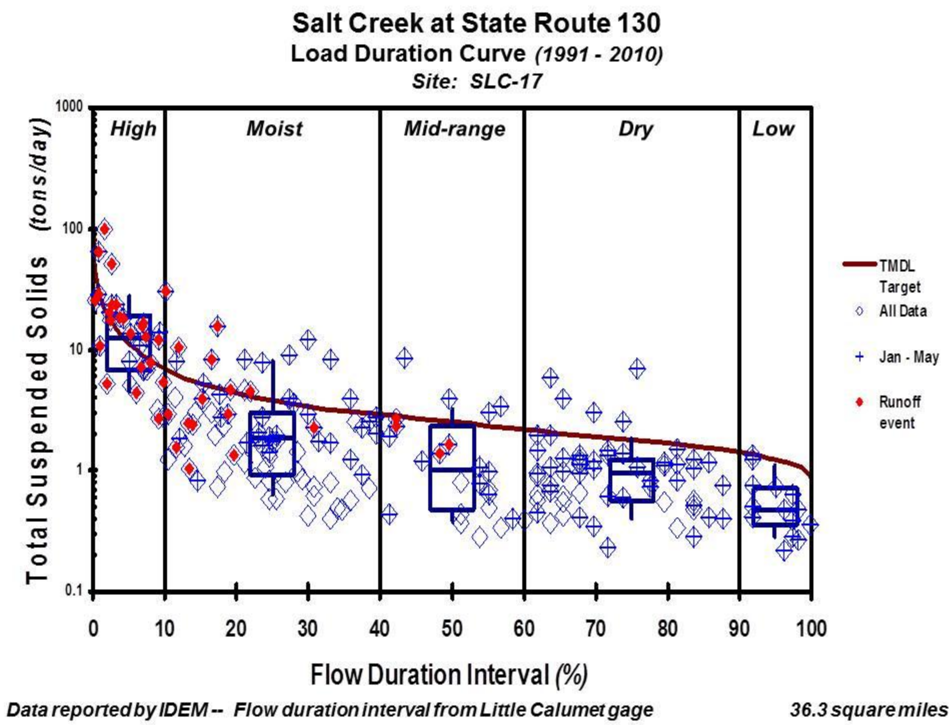


Figure 2-6. TSS load duration curve -- Salt Creek at State Route 130.

Figure 2-7. Effect of stormwater on East Branch Beauty Creek.

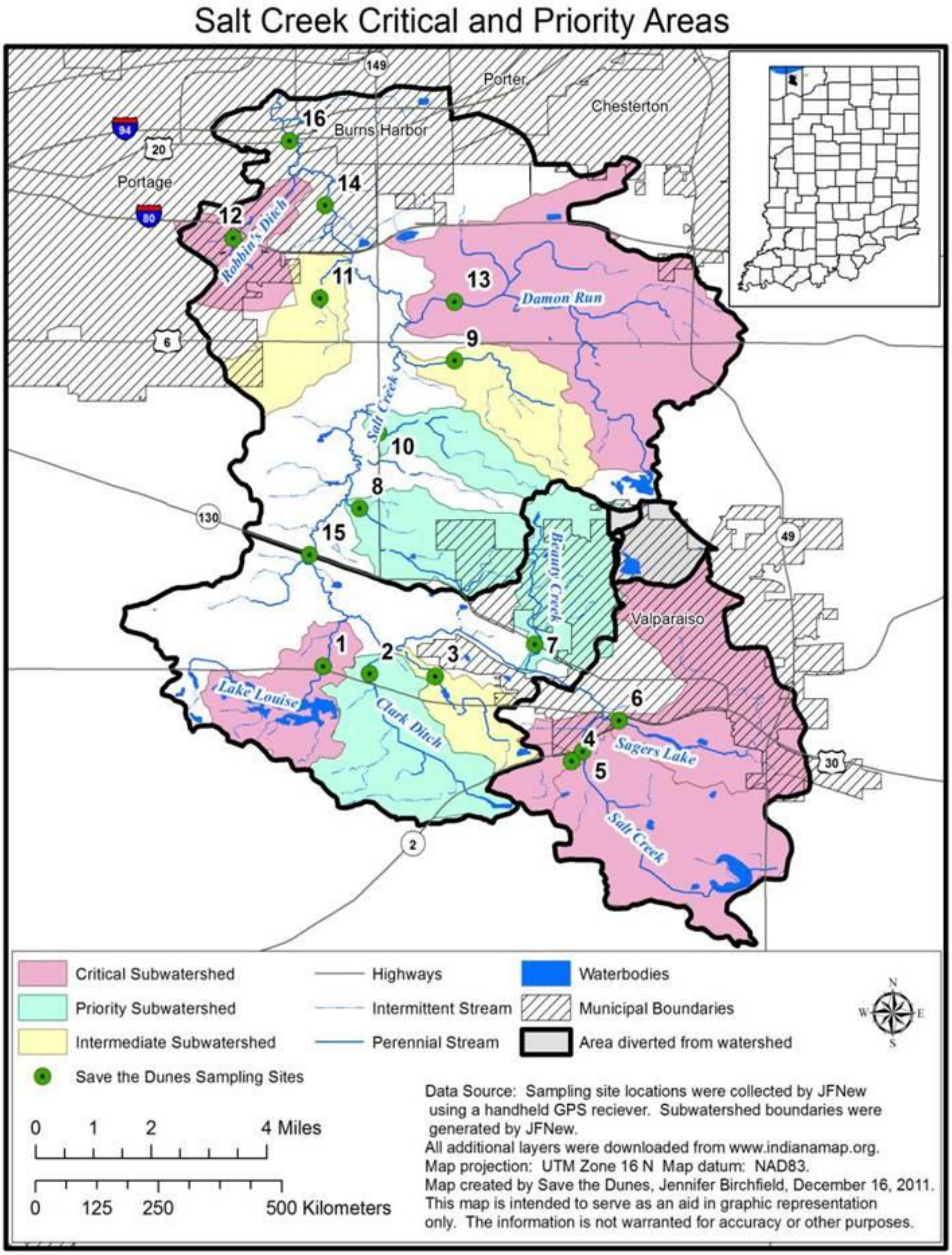


Figure 2-8. Salt Creek watershed management areas.

Two other critical areas of the Salt Creek watershed are of interest for future investigation. The Sager's Lake subwatershed is a critical area due to flashy flows and elevated *E. coli*. The subwatershed drains a large portion of the City of Valparaiso. Save the Dunes and the City of Valparaiso have partnered to retrofit and naturalize detention basins and to install roadside bioswales in the Sager's Lake subwatershed. The Sager's Lake subwatershed is also of interest to Porter County due to flooding concerns.

The Damon Run subwatershed is a critical area due to elevated total phosphorus and impaired biotic communities. The subwatershed consists primarily of agricultural and forested lands with increasing amounts of residential development in recent years. Porter County has received complaints of flooding in the area and concern; the additional runoff derived from development exceeds the ability of Damon Run to handle. A new hospital was constructed and additional residential, commercial, and institutional developments are planned adjacent to the site. Save the Dunes continues to advocate for conservation design and LID principles as this development occurs. The anticipated development and existing flooding concerns prompted additional drainage studies of the area by Porter County.

2.1.2 Beauty Creek

Beauty Creek is a tributary to the Salt Creek watershed. The creek begins northwest of the City of Valparaiso and flows south through the western portion of the city before entering the Salt Creek mainstem just downstream of the City of Valparaiso. Save the Dunes has one long-term sampling location located on Beauty Creek: north of State Road 130 in western Valparaiso. Beauty Creek ponds where the east and west branches converge just upstream of the sampling site. Save the Dunes has been unable to set up long-term sampling sites upstream of this confluence, as most accessible sites on the tributaries are dry between storm events. Severe erosion has been noted at several locations along the creek, upstream of the confluence of the two branches (Figure 2-9).

Beauty Creek was selected for the pilot study for several reasons. The watershed is designated as a priority area of the Salt Creek watershed. Data indicate poor biological communities in Beauty Creek. The City of Valparaiso is interested in Beauty Creek due to concerns over severe erosion, sometimes threatening property along the creek. Plans to separate combined sewers in the area will send additional water to Beauty Creek, potentially exacerbating erosion.

There are a number of stormwater management efforts occurring in the Beauty Creek watershed. For instance, in the spring of 2008, Save the Dunes, the City of Valparaiso, and the Valparaiso Parks Department partnered to install rain gardens adjacent to Beauty Creek at Forest Park Municipal Golf Course. The first garden is approximately 9,000 square feet and accepts runoff from a 0.8 acre parking lot, one-half of the roof of a clubhouse and some surrounding turf area for a total contributing area of about 1.9 acres. The second garden is approximately 6,000 square feet and accepts runoff from approximately 1.6 acres of woodland and 7.3 acres of turf. Save the Dunes and the Valparaiso Parks Department also planted riparian gardens in critical areas at the Forest Park Golf Course and at the Forest Park Picnic Area. Save the Dunes also partnered with residential property owners in the Beauty Creek watershed to install two rain gardens and an educational sign at a residential yard in the Beauty Creek subwatershed in 2009. The gardens are 400 and 300 square feet and collect runoff from a combined total of 2,000 square feet. Since that time, Save the Dunes has been contacted by additional residential property owners in the subwatershed with interest in rain gardens. In 2012 Save the Dunes partnered with the City of Valparaiso to stabilize severely eroding streambanks along the east branch of Beauty Creek.

Figure 2-9. Stormwater related concerns in Beauty Creek.

The City of Valparaiso conducted the *Chautauqua Park Drainage Study* in 2011 to determine economical and creative solutions to significantly reduce flooding issues that occur in the area Chautauqua Park area. The 210 acre Chautauqua Park neighborhood is located southwest of downtown Valparaiso, bounded by Yellowstone Road to the west, Grand Trunk and Western Railroad to the north, Campbell Street to the east, and Lincoln Way to the south. The area, which is just southeast of the Beauty Creek subwatershed, is presently served by combined sewers, but the City has determined that complete separation of the system is cost prohibitive at this time. Alternative solutions that were analyzed include a combination of new stormwater conveyance systems and detention basins that will manage stormwater runoff. By managing stormwater with these implementations, the city hopes to not only decrease flooding-related issues in the area but to reduce the potential for inflow and infiltration into their combined sanitary sewer system. The new stormwater system will divert water that previously entered the combined sewer system to Beauty Creek. While this project will reduce flooding and CSOs, it will add stormwater to Beauty Creek, which already shows signs of erosion and impairment due to stormwater.

Also in the Chautauqua Park neighborhood, the City of Valparaiso received a grant from the U.S. Forest Service for the Valparaiso Payment for Ecosystem Services (PES) green infrastructure project. Additional funding was provided by the Northwest Indiana Regional Development Authority and the City of Valparaiso. The project attempts to determine what encourages private property owners to install green infrastructure on their property, to ultimately help reduce stormwater runoff to public areas. Neighborhood residents were asked to bid the amount they were willing to pay for professionally installed rain barrels and rain gardens. As a result of this project, 60 rain barrels and 11 rain gardens have been installed in the Chautauqua Park neighborhood.

2.2 Study Area

A pilot area was selected from the larger Beauty Creek subwatershed for this study. The primarily residential pilot area was selected because it includes a mixture of newer and older development with varying lot sizes and degrees of stormwater retention, a high school with significant impervious area, and municipal parks.

2.2.1 Key Questions

In contemplating the use of *SUSTAIN* to assess BMP opportunities and constraints, key questions can guide planning efforts. These questions bracket the range of viable options and ultimately help frame stormwater management decisions. Relative to this pilot effort, key questions include:

- What amount of the high school parking area could be converted to bioretention or pervious pavement to meet a volume reduction target? Where would be the best locations to target?
- Do bioswales offer viable options? Are there any suitable locations where infiltration trenches could be used (e.g., in large parking areas)?
- How many homes need to install rain gardens to achieve noticeable reductions in stormwater volume? Where would be the best locations to target?
- What are some treatment train design alternatives (including use of rain barrels)?
- What is the minimum acceptable operation and maintenance needed?
- How do assumptions associated with the different scales affect information needed by stormwater program managers to make subsequent decisions regarding development of cost-effective strategies?

2.2.2 Residential Area Evaluation

A portion of the Beauty Creek watershed was selected as the pilot area (Figure 2-10). Encompassing approximately 450 acres, entirely served by storm sewer, the pilot area drains generally from east to west ultimately discharging into Beauty Creek. There are currently no known regional stormwater treatment facilities, although planning is underway for construction of one just west of the pilot area. Land use is primarily residential (Table 2-1). The project area also includes several schools, a portion of the Forest Park Golf Course, a large public park, and several commercial areas. The overall pilot area is 34 percent impervious (156 acres of imperviousness). Table 2-2 summarizes the impervious area by subcatchment.

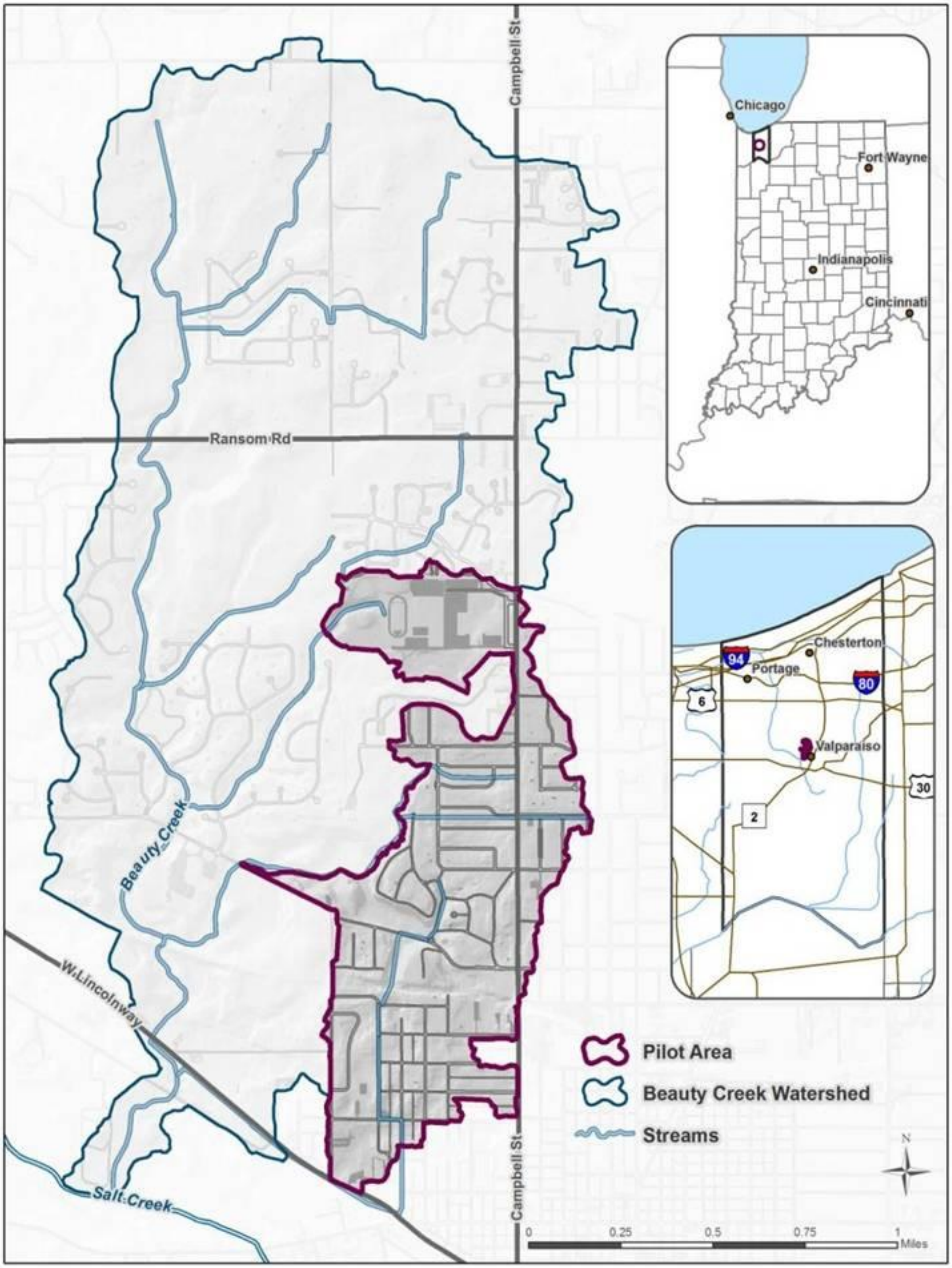


Figure 2-10. Beauty Creek pilot area.

Soils in the Beauty Creek pilot area are till; silt- clay with stones of mixed size and material and with sparse pockets of sand. Soils data identify low permeability and urban soil units (Figure 2-11). The Valparaiso High School is mapped as Undorthents, which is typically fill material. There is an area mapped as Fluvaquents, which includes a historical streambed and associated flood prone areas. Mapped soils include hydrologic soil groups C and C/D, which are assumed to extend throughout the entire pilot area. These soils tend to have low permeability and are likely compacted due to urban land uses. Topography is mainly flat throughout the Beauty Creek pilot area. A portion west of Campbell Street and north of Harrison Boulevard includes tree covered slopes and small ravines that reflect the glacial moraine topography.

Table 2-1. Land cover from the 2006 NLCD

Description	Area (acres)	Percent of watershed (%)
Developed Open Space	101.8	22.4%
Developed Low Intensity	277.1	61.0%
Developed Medium Intensity	49.4	10.9%
Developed High Intensity	10.0	2.2%
Deciduous Forest	11.2	2.5%
Shrub Scrub	0.2	0.04%
Grassland Herbaceous	0.09	0.02%
Cultivated Crops	0.03	0.01%
Total	**454.3**	100.0%

Table 2-2. Impervious area summary

Subcatchment name	Subcatchment ID	Area (acres)	Impervious area (acres)	Percent impervious (%)
Sheffield	2002	77	29	37%
Roane	2003	32	13	41%
Northview	4003	50	17	34%
High School	3002	79	32	40%
Harrison	4002	99	22	22%
Chautauqua South	4000	65	25	38%
Chautauqua North	4001	51	19	38%
Total		**454.3**	**156.0**	**34%**

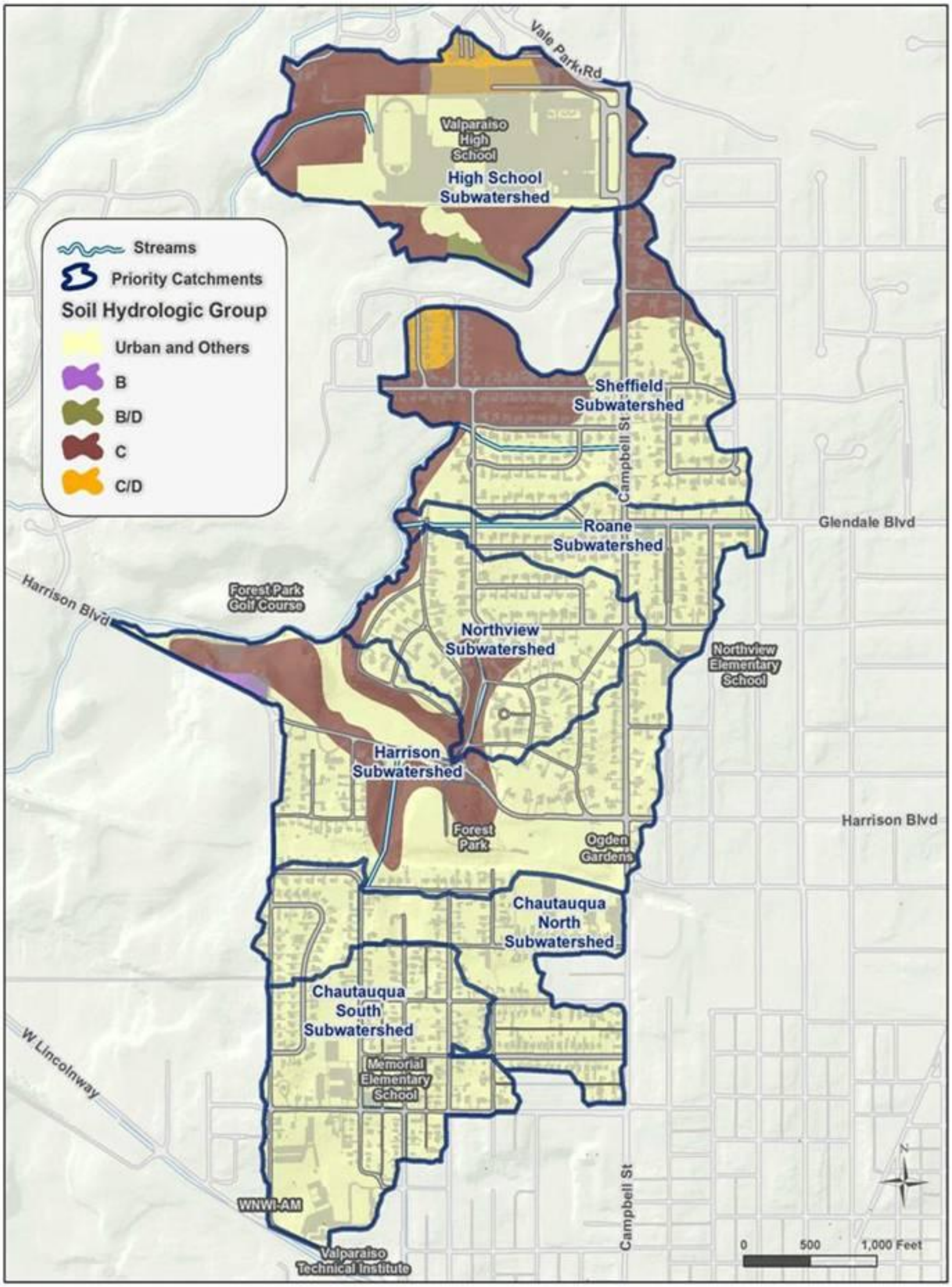


Figure 2-11. Beauty Creek pilot area catchments and soils.

Residential areas, representing nearly 290 acres (or over 60 percent of the test subwatershed) were evaluated for common characteristics. Key characteristics examined include average:

- Parcel size
- Roof area
- Driveway area
- Front yard area
- Width of green space between street and sidewalk (if present)

This resulted in the identification of four separate residential categories (Figure 2-12). The majority of the residential areas are served by sidewalks with varying widths of green space between the back of the curb and the sidewalk. Table 2-3 summarizes the key characteristics of each mapped residential area. General conclusions are made about each residential area below with regards to BMP applicability. Proposed BMP areas on Figure 2-12.

Table 2-3. Summary of residential area characteristics

Residential area	Total area (acres)	Number of homes	Average parcel size (sq ft)	Average front yard (sq ft)	Width of green space between curb and sidewalk (feet)	Average roof area[a] (sq ft)	Average driveway area (sq ft)
A	60.1	139	14,694	3,065	No sidewalks	2,468	1,350
B	19.9	95	9,059	790	8 to 10 feet	1,301	590
C	159.6	490	11,901	1,862	4 to 5 feet	2,035	536
D	49.5	159	8,700	1,368	> 6ft, but few of them	1,492	688
a. Area includes garage roof when attached to home							

Residential area A includes the largest homes with attached garages. There are no sidewalks in this area, and the average front yard is 3,065 square feet in size. This residential area offers the opportunity to install bioretention areas that can treat rooftop runoff as well as roadway runoff in front yards. In addition, large front yards can also be used for privately owned rain gardens. There are also large wooded areas present in this area.

Residential area B is located in the southeast portion of the pilot area and includes homes on small lots with very small front yards. Garages are typically detached and outbuildings are common throughout. There are backyard alleys which serve some of the homes. Due to the small front yard area (790 square feet), privately owned rain gardens will not be applicable to the majority of properties. There is a significant amount of green space between the back of the curb and sidewalk in this residential area that can be utilized for roadside bioswales.

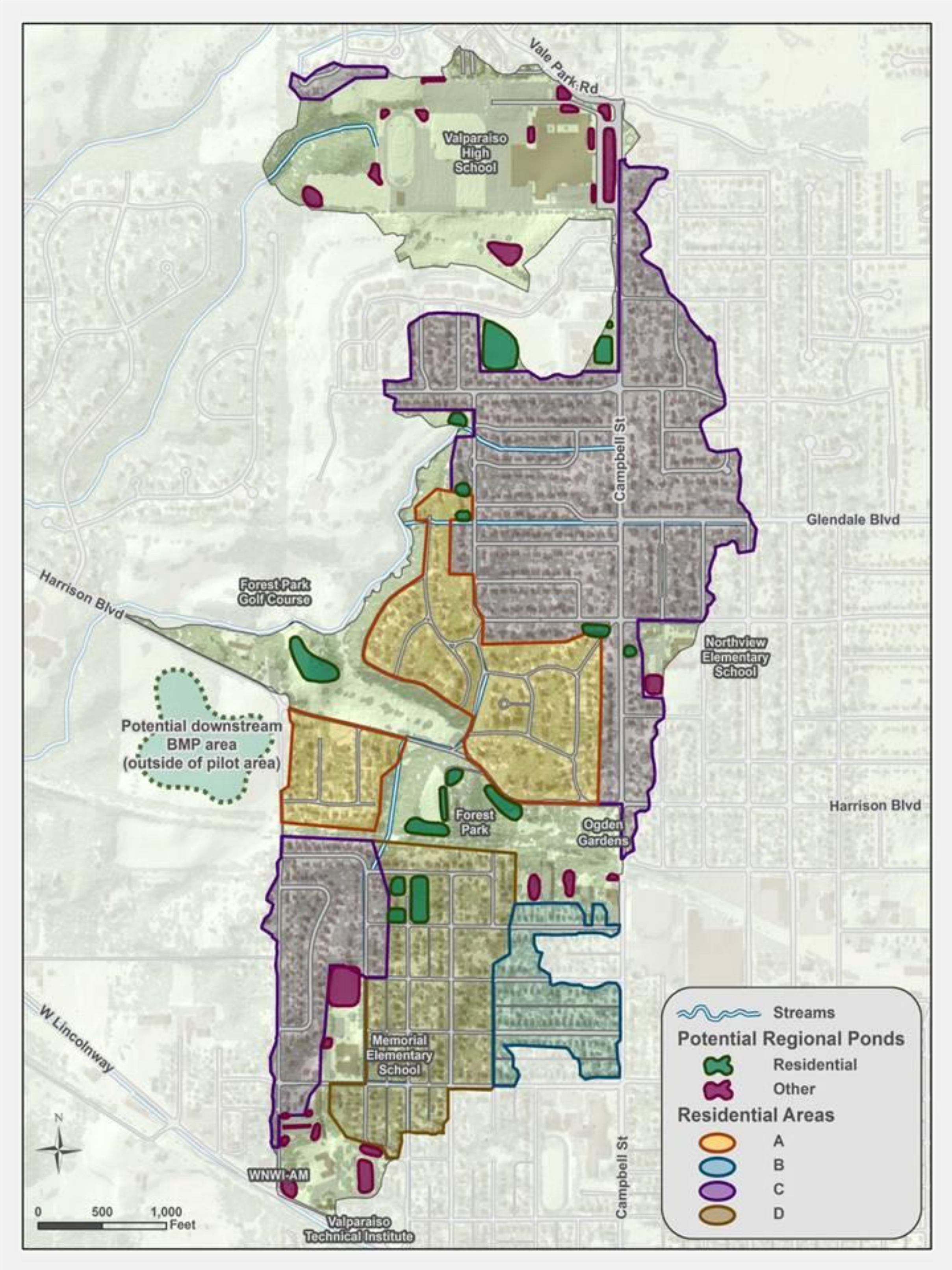


Figure 2-12. Residential area evaluation.

Residential Area C makes up the majority of the pilot area (55 percent) and has a mix of attached and detached garages. Sidewalks are common throughout this area. Front yards (between sidewalk and front of home) average 1,862 square feet, thereby making privately owned rain gardens a reasonable BMP alternative. There is typically insufficient space between the sidewalk and curb to install bioswales. Campbell Street is located in this area and has an average width of 40 feet with 8 to 14 feet of green space between the curb and sidewalks, which presents an opportunity for a green street design.

Residential Area D includes a mix of homes with attached and detached garages. Sidewalks are found in portions of the area. Front yards on average are well-sized, and therefore privately owned rain gardens could be implemented in this area. Because sidewalks are not consistently present this residential area, bioswales and bioretention areas not assumed to be applicable in this area. Further on-site evaluation of this residential area would likely result in applicable areas for bioretention.

2.3 Five-Step Process

Several activities included in this project support targeting and optimization. In particular, focus is placed on evaluating and design of stormwater BMPs (both structural and non-structural) that improve water quality conditions surrounding documented problems. A key objective is to prioritize source area and delivery mechanisms, in order to ensure effective use of available resources. The process used in this pilot effort to evaluate stormwater management opportunities involves five general steps. These include:

Step 1 - Establish baseline conditions
Step 2 - Identify potential BMPs
Step 3 - Determine BMP configurations and performance
Step 4 - Identify BMP costs
Step 5 - Perform BMP optimization analysis

Figure 2-13 presents a general flow diagram of the process, identifying considerations and inputs. Basically, the process employed uses information on BMP effectiveness coupled with cost information to identify the most economical alternatives through an optimization step. The goal is to target specific implementation activities that address water quality problems related to stormwater.

Step 1 – Establish Baseline Conditions. The initial step in evaluating and selecting BMPs to achieve stormwater management program goals is to establish baseline conditions. Baseline conditions reflect the existing flow conditions and pollutant loading from a stormwater source. Identifying and understanding baseline conditions provides a starting point from which improvements are made and progress is measured (i.e., BMP effectiveness is measured against the established baseline conditions).

Step 2 – Identify Potential BMPs. In the second step, baseline condition information is coupled with local factors to generate a list of potential BMPs. Information about baseline conditions provides a benchmark that helps stormwater planners identify potential BMPs, or combinations of BMPs, to achieve overall program goals. In its simplest form, for example, the runoff volume produced by a certain design storm can be used to estimate detention needs. While identifying and selecting potential BMPs, it is important to understand other factors that might affect successful BMP implementation. These factors include environmental, physical, social, and political considerations.

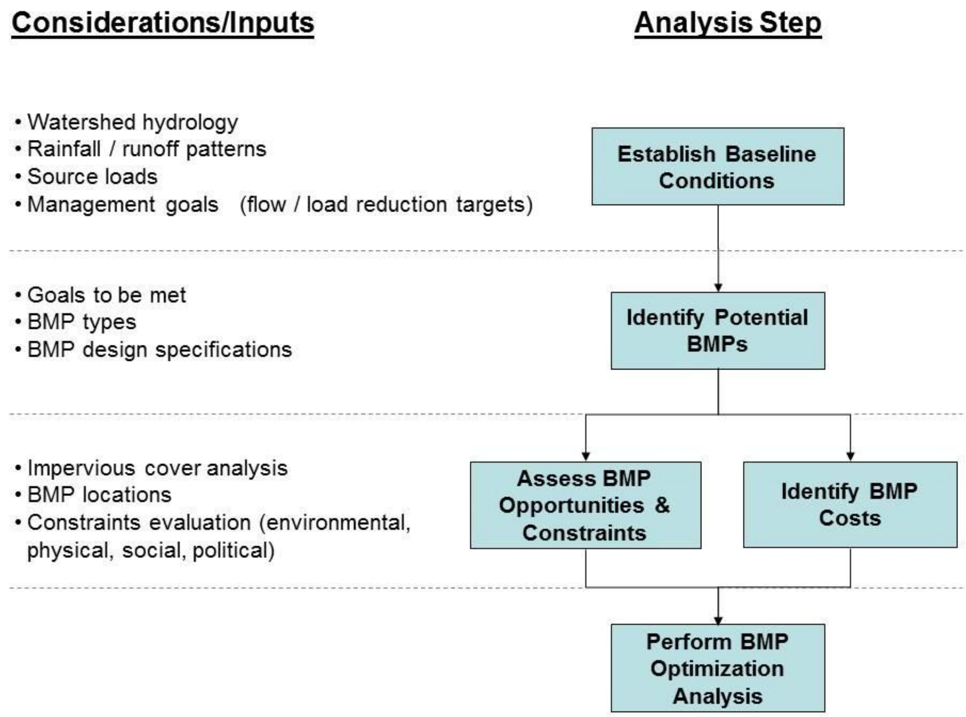


Figure 2-13. Process for BMP targeting and optimization.

Step 3 – Determine BMP Configurations and Performance. The goal of this step is to evaluate the list of potential BMPs and determine their overall performance at the watershed-scale. The intent is to identify options prior to selecting final BMP strategies. Assessing configuration opportunities, stormwater planners can examine the expected performance of potential BMPs to help select those that will meet the goals identified in Step 1. Although challenging, this activity is essential to selecting BMPs with the most potential for making progress toward management objectives. For purposes of describing the overall process, this is discussed as a separate step after compiling the list of possible BMPs. However, stormwater planners can make assumptions and determinations about BMP configuration and performance while generating the list.

Step 4 – Identify BMP Costs. Identifying BMP costs is an important undertaking for stormwater planners. Resource constraints can affect the number and type of BMPs that can be used to achieve progress toward program goals. At a minimum, stormwater planners should compare costs and expected pollutant reductions to ensure the final suite of BMPs will provide the most reductions for the least amount of money. For stormwater planners engaged in a more rigorous BMP optimization analysis, cost information on potential BMPs is essential for developing cost-effectiveness ratios (i.e., cost per unit of pollutant removed) to compare different BMPs for one type of land use or across several types of land uses.

Step 5 – Perform BMP Optimization Analysis. At this stage, stormwater planners have identified the suite of feasible BMPs based on site-specific needs, goals, opportunities and constraints. Depending on the size of the planning area, the implementation goals and the resources available, there could be any number of combinations of BMP types and locations to meet goals. A goal of targeting and optimization is to examine management strategies based on opportunities consistent with site suitability considerations. For example, slope and soil infiltration rates are key factors that affect successful performance of structural BMPs.

To select the final BMP strategy, stormwater planners generally evaluate, prioritize or rank the potential BMPs based on relevant decision criteria, either qualitatively or quantitatively. Decision criteria may include short-term and long-term costs, BMP performance, expected progress toward watershed goals, and compatibility with other planning priorities and objectives. Depending on the area and number of BMPs needed, a stormwater planner might use a qualitative evaluation of potential BMPs and targeted locations based on professional and local knowledge. Simple spreadsheet analysis could also be employed to identify the most appropriate and cost-effective scenario. While adaptive management can support the short-term implementation of priority BMPs with subsequent evaluation and modification, a stormwater planner tries to identify the most effective scenario first to minimize the need for additional BMPs and associated implementation costs. Therefore, the level of detail for the evaluation to select final BMPs can be driven by the benefit of the additional analyses compared to the potential costs to correct ineffective implementation.

3. Establish Baseline Conditions

Effective implementation planning starts with a review of baseline conditions and watershed-scale factors that contribute to documented water quality problems in the Salt Creek watershed. In particular, a sound understanding of basic hydrologic processes at work in this drainage is the heart of stormwater management. Climate is the dominant driver of baseline conditions. A key component of protecting water resources is keeping the water cycle in balance (SEMCOG 2008).

The water cycle is a natural, continuous process that can be generalized as the movement of rainfall from the atmosphere to the land, then back to the atmosphere. The balanced water cycle of precipitation, evapotranspiration, infiltration, groundwater recharge, and stream base flow is a key part of sustaining fragile water resources (Figure 3-1). When identifying and establishing baseline conditions, a critical part of the analysis involves an assessment of rainfall patterns and watershed characteristics that affect the resultant runoff. Source areas and delivery mechanisms that will be the focus of targeted BMPs are driven by watershed response to precipitation. Describing the frequency and magnitude of rain events in conjunction with an analysis of associated runoff are key considerations in establishing baseline conditions and for eventually determining appropriate stormwater management strategies.

Approximately 36 inches of precipitation falls on the Salt Creek watershed each year, based on climate records collected from 1949 – 2010 at the Valparaiso Airport. This precipitation results in approximately 16 inches of runoff, based on USGS stream flow data for the Little Calumet River during that same period. Although runoff at the Little Calumet gage does not represent a completely undeveloped area, it does provide information that can be used to frame a discussion of baseline conditions for the Salt Creek watershed. This includes a basic review of precipitation patterns and local factors that influence runoff.

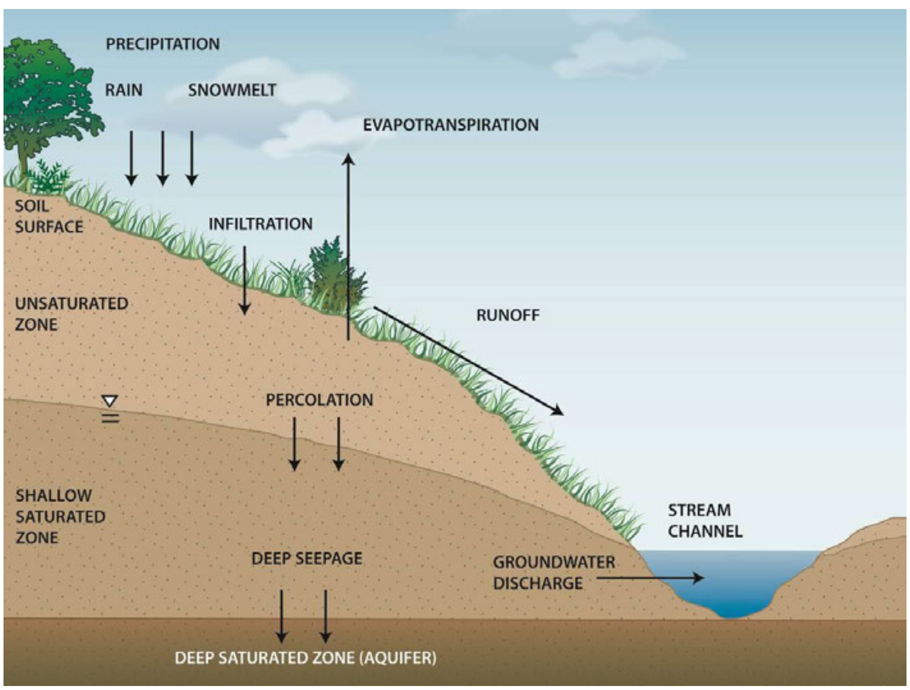


Figure 3-1. Water cycle.

3.1 Precipitation Patterns

Precipitation is a major factor considered in stormwater management because developing effective management strategies and implementing green infrastructure practices typically results in keeping as much stormwater on site as possible. Thus, an examination of precipitation patterns, which result in stormwater, is a key part of stormwater implementation planning. Annual variation, for example, is one consideration (as shown in Figure 3-2 for the Valparaiso climate station). Many BMPs are designed using storm frequency data (storm frequency is based on the statistical probability of a particular storm occurring in a given year). This information can be obtained through the National Weather Service (NWS) Precipitation Frequency Data Server (NWS 2004).

Recurrence intervals available on the server range from 1 to 100 years. This data is often used to address local stormwater regulations that include peak discharge control (Dorsey et. al 2009). The Critical Storm Method provides one approach to examine peak discharge control needs. This method requires rainfall depth for the 1 through 100 years, 24-hour events. Table 3-1 summarizes rainfall depth – duration frequency information for the Valparaiso station.

Stormwater source inputs to receiving waters are ultimately a function of rainfall and snowmelt. Not all storms are equal; differences in frequency, magnitude, and duration play a major role in determining appropriate implementation strategies. Although large storms are critical in terms of flooding, most rainfall in the Valparaiso area actually occurs in relatively small storm events. An examination of precipitation patterns is a key part of stormwater implementation planning. This includes an analysis of rainfall intensity and timing to assess BMP performance relative to water quality goals.

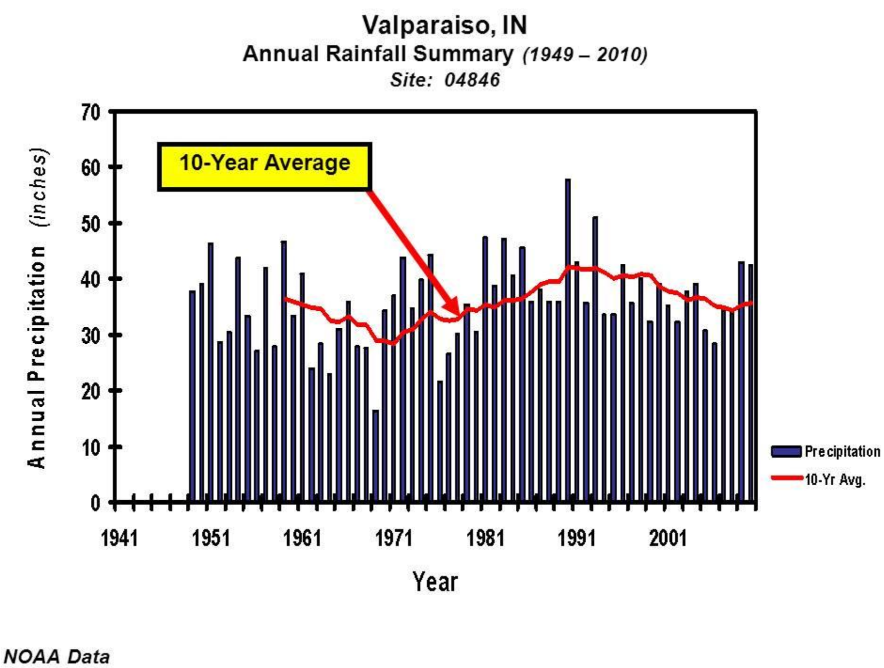


Figure 3-2. Annual precipitation summary for Valparaiso.

Table 3-1. Rainfall depth – duration frequency for Valparaiso

Recurrence Interval *(years)*	**Precipitation Frequency Estimates *(inches)***			
	Duration *(hours)*			
	3	**6**	**12**	**24**
1	1.43	1.72	2.03	2.36
2	1.74	2.10	2.45	2.89
5	2.24	2.70	3.14	3.72
10	2.67	3.22	3.73	4.42
25	3.26	3.97	4.56	5.42
50	3.77	4.60	5.28	6.27
100	4.31	5.28	6.03	7.19
	Data for Valparaiso retrieved from: http://hdsc.nws.noaa.gov/hdsc/pfds/			

While design storms provide a valuable long-term planning tool, the distribution of rainfall event depth is also an important factor. The effect of different rainfall patterns on runoff and stormwater source loads (and subsequent BMP performance) should be accounted for in the technical analysis. Figure 3-3 illustrates one method used to characterize rainfall distribution for the Valparaiso precipitation gage. As shown in Figure 3-3, seven percent of measurable precipitation events in Valparaiso exceed one inch over a 24-hour period.

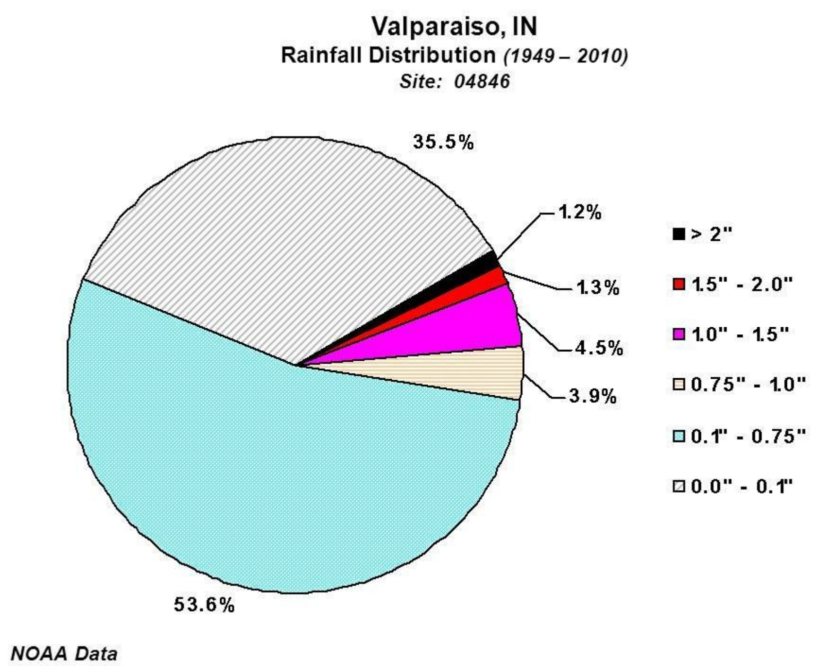


Figure 3-3. Rainfall distribution for Valparaiso.

State and local agencies often define critical event rainfall depths in the stormwater management manuals or ordinances. For example, Ohio's WQv establishes a metric that guides design of post-construction BMPs (e.g., filtration, infiltration, detention) to achieve targets for volume and peak rate controls. In Ohio, the WQv has two protection objectives: reducing the pollutants suspended in runoff and reducing the energy of common storm events responsible for most channel erosion (Ohio Department of Natural Resources 2006). Basically, WQv represents the critical event used to calculate stormwater quantity and quality impacts of new development and redevelopment. The water quality volume is calculated using the following equation, adapted from *Urban Runoff Quality Management* (ASCE / WEF 1998):

$$WQv = C * P * (A/12)$$

where:

C = runoff coefficient
$= 0.858*i^3 - 0.78*i^2 + 0.774*i + 0.04$
i = watershed imperviousness ratio *(percentage divided by 100)*
P = amount of precipitation occurring in a 24-hour period *(inches)*
A = area treated by the BMP(s) *(acres)*

Source loads associated with many small storms can be equally important in terms of their effect on receiving streams. In the case of Valparaiso, 93 percent of the measureable precipitation events are at or below one inch. For instance, there may be a critical precipitation depth where measurable stormwater loads begin to occur, depending on subwatershed characteristics. From this perspective, BMP targeting and optimization efforts should examine issues such as the full range of flows associated with all storms, as well as flows associated with the design storms such as WQv.

Related to the identification of design storms, it is useful to examine the cumulative frequency distribution of 24-hour precipitation events. A frequency distribution of daily precipitation data can be viewed in several ways (Figure 3-4). The first is to determine the frequency interval by considering all days (whether or not there was measurable precipitation), as shown by the lower curve in Figure 3-4. This approach allows for comparison with flow duration curves because daily precipitation values are sorted from high to low; the total number of days is used to calculate to recurrence percentage.

Over the past few years, there has been an increased emphasis on volume-based hydrology in stormwater management (Reese 2009). The premise is that reductions in stormwater volume will lead to reductions in pollutant loading (National Research Council 2008). USEPA technical guidance has identified using the 95^{th} percentile rainfall event as one option to meet stormwater runoff reduction requirements for Federal facilities (USEPA 2009). The 95^{th} percentile storm is calculated through the use of a frequency distribution of all daily rainfall values with small precipitation events removed (i.e., those less than 0.1 inches). This design volume captures all but the largest five percent of storms, as depicted by the upper curve in Figure 3-4. For the Valparaiso gage, this corresponds to 1.41 inches.

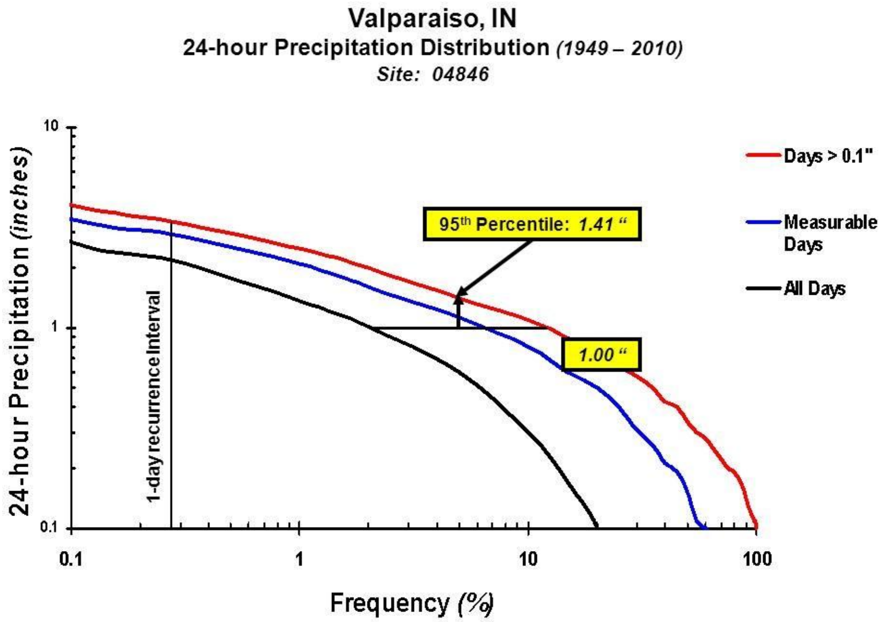


Figure 3-4. Cumulative frequency distribution of 24-hour precipitation events for Valparaiso.

3.2 Hydrology

Flashy flows are typical in the Salt Creek watershed, including the pilot area, because the local hydrology is controlled by the local, unique climate conditions. During flashy flows, a stream responds to and recovers from precipitation events in a very short timeframe. Limited flow data makes it difficult to describe the full range of hydrologic conditions the Salt Creek watershed may experience. Although a long term stream gage is not currently active on Salt Creek, the U.S. Geological Survey (USGS) is monitoring flow in the Little Calumet River at Porter. Figure 3-5 and Figure 3-6 show rainfall-runoff patterns over a six-month period with data from the Valparaiso precipitation station and the USGS Little Calumet flow gage.

Flow duration curves are an effective method to characterize hydrologic conditions and are an important component of an overall hydrologic analysis. Duration curves provide a quantitative summary that represents the full range of flow conditions, including both magnitude and frequency of occurrence (USEPA 2007). Development of a flow duration curve is typically based on daily average stream discharge data. A typical curve runs from high flows to low flows along the independent axis (x-axis), as illustrated in Figure 3-7.

This graph depicts a flow duration curve for the Little Calumet River. The duration curve shown in Figure 3-7 is expressed as unit area flows (i.e., inches per day) for direct comparison between other sites. Note the flow duration interval of 40 associated with a stream discharge of 0.033 inches of runoff per day (i.e., 40 percent of all observed stream discharge values equal or exceed 0.033 inches of runoff per day).

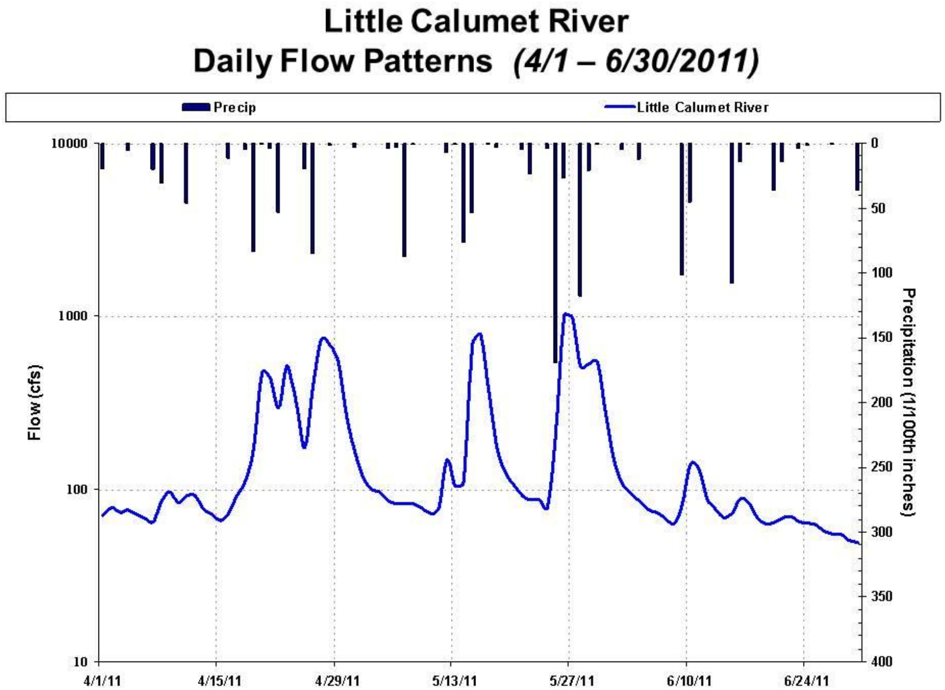


Figure 3-5. Salt Creek watershed rainfall – runoff patterns (April – June 2011).

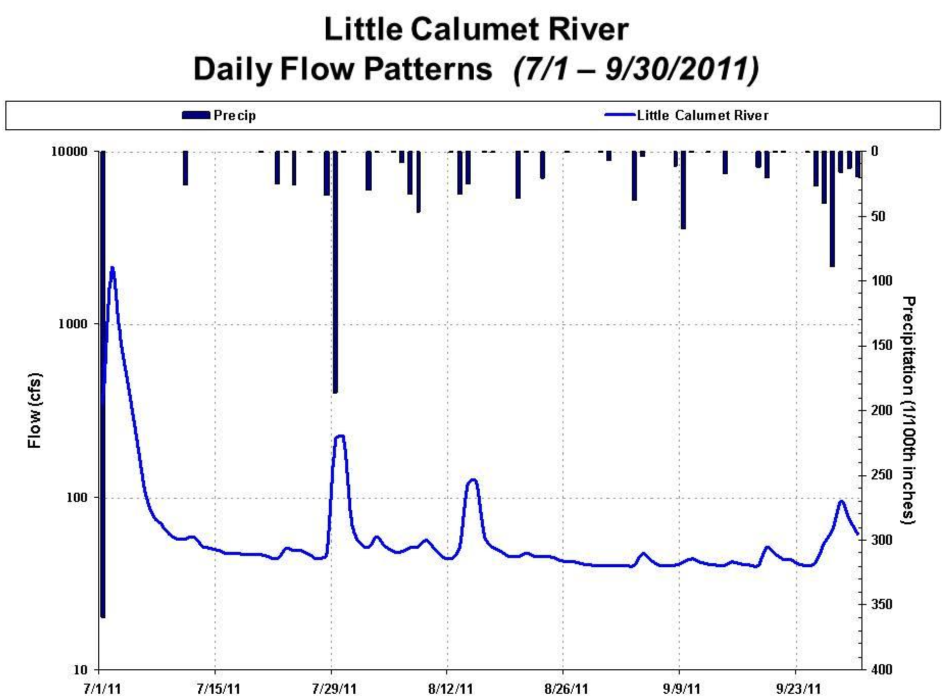


Figure 3-6. Salt Creek watershed rainfall – runoff patterns (July – September 2011).

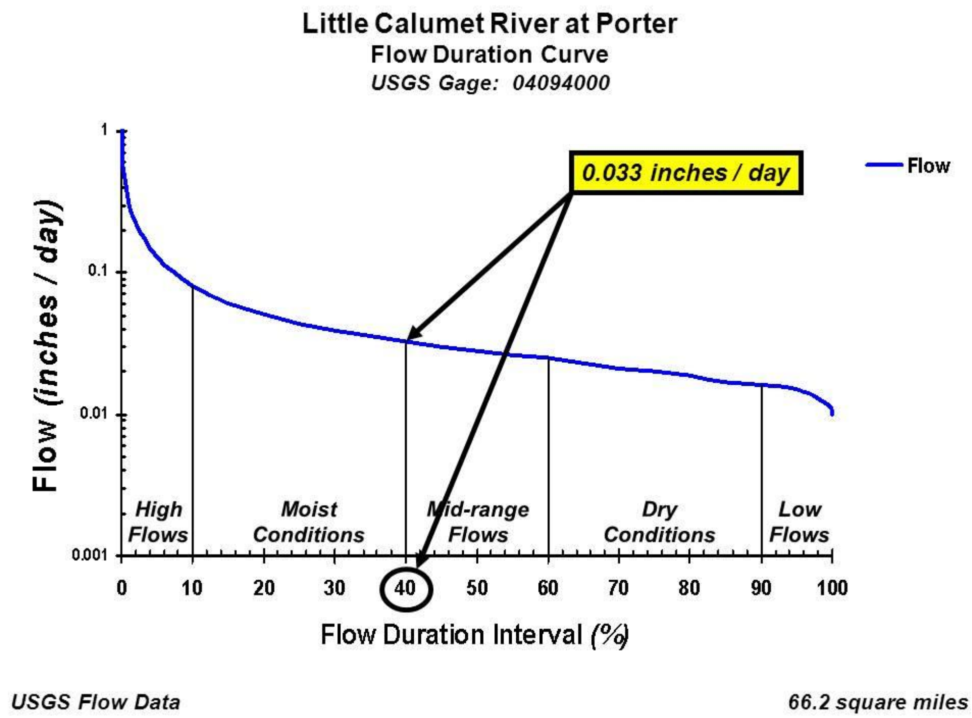


Figure 3-7. Unit area flow duration curve for Little Calumet River.

3.3 Rainfall - Runoff Model

Watershed response to precipitation events is an equally important part of BMP targeting and implementation. While rainfall and snowmelt act as driving forces, the resultant runoff serves as a key focal point for stormwater management programs. Hydrologic measures such as total runoff volume, peak flow rate, runoff hydrograph, and duration curves are often used to guide the design of protection, control, and restoration strategies associated with stormwater management.

A key objective of analyzing runoff patterns is to prioritize source area and delivery points / mechanisms to help ensure effective BMP targeting. Figure 3-8 illustrates the utility of flow duration curves in assessing the effects of land use change on watershed hydrology. In this example, land use changed dramatically from 1950 to 1984. The conversion from low density to high density residential increased both the magnitude and frequency of high flow events. As discussed earlier, implementation of LID practices strive to minimize the effect of altered hydrology.

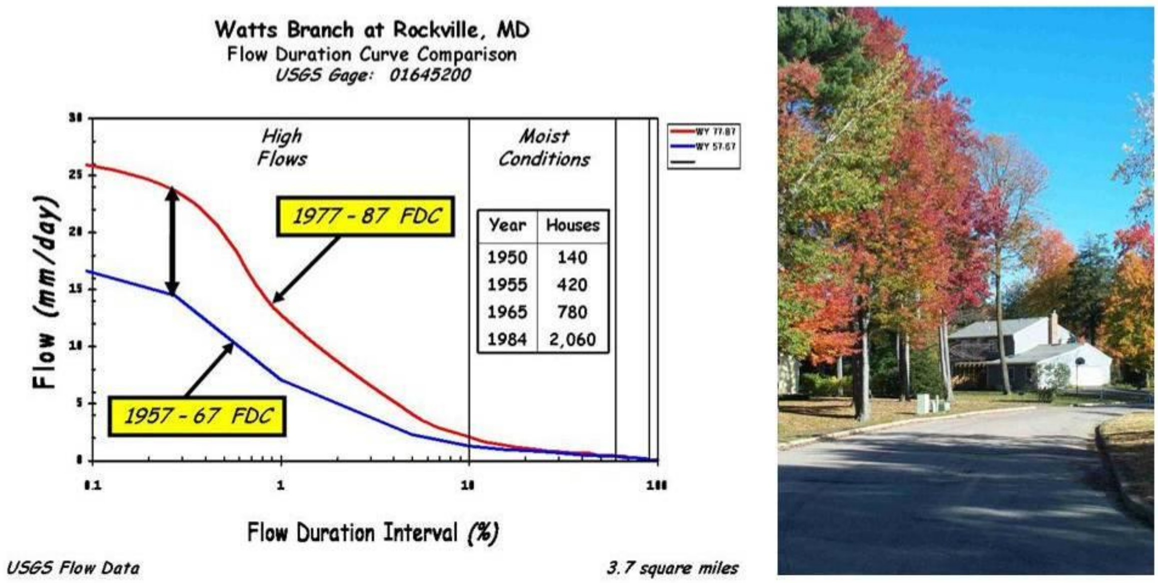


Figure 3-8. Effect of land use change on flow duration curve.

Ideally, real-time, fine-scale monitoring of stream flow and water quality could guide the design of BMP implementation strategies. However, the costs associated with this level of data collection are generally much greater than available resources. For this reason, computer models are often used to develop information that describes watershed response to precipitation events.

Figure 3-9 illustrates a simple conceptualization of the relationship between rainfall – runoff models and their use in assessing BMPs. In this hypothetical scenario, rain falls on the land producing runoff (depicted by the LAND box). The resultant runoff is routed to the stormwater BMP for subsequent evaluation of its performance.

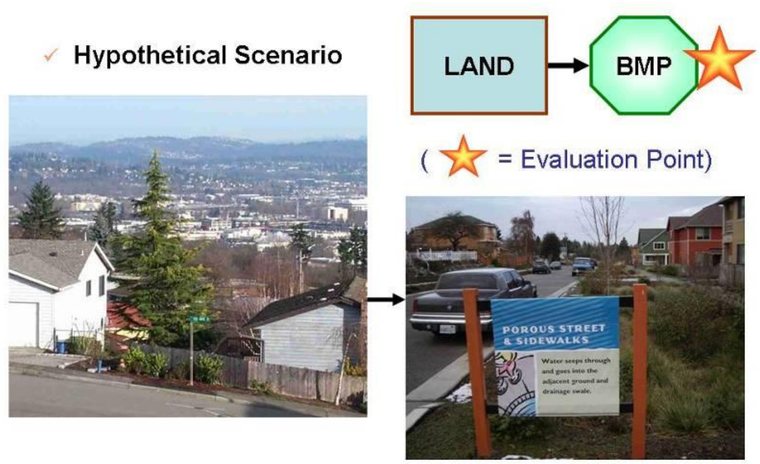


Figure 3-9. Stormwater modeling concepts.

There is a wide variety of models available that have been used to assistance stormwater management activities in describing runoff patterns. Similarly, the approaches range from simple to complex, and include:

- Stormwater Management Model (SWMM)
- Hydrologic Simulation Package FORTRAN (HSPF)
- LSPC
- P8 Urban Catchment Model (P8-UCM)
- Source Loading and Management Model (SLAMM)
- HEC Hydrologic Modeling System (HEC-HMS)
- SCS / NRCS Win TR-20 and Win TR-55

This above list is by no means complete. However, it does reflect the most common models used to address urban runoff concerns.

A watershed model for land units in the Beauty Creek drainage was developed as part of this project. The model was designed to investigate the potential benefits of BMP implementation in the watershed. Simulated surface runoff serves as a primary input for the development of the *SUSTAIN* BMP implementation model for select catchments in the Beauty Creek watershed.

A key feature of the watershed model development was a target watershed approach. This approach identified drainages located in the greater Salt Creek watershed that have similar land use and soil characteristics as the Beauty Creek drainage. Calibrated model parameters were developed for the target watershed and simulated daily average runoff volumes to be used as input to the Beauty Creek *SUSTAIN* model.

The target watershed approach is needed because conditions in the Beauty Creek watershed preclude an out-of-the-box watershed model application to simulate watershed hydrology. Runoff in the watershed is managed with an extensive network of storm retention basins. Accurate representation of the impact of those stormwater management systems on hydrology would require detailed analysis of detention pond volumes and orifice designs. In addition, the only flow monitoring conducted in the watershed has been done downstream of a large area of wetlands, which tend to mute the rainfall-runoff response of stream flow. As a result, typical rainfall-runoff relationships would not be reflected in the available data.

3.3.1 Target Watershed Selection

A comparison of flow duration curves for drainages within the Salt Creek watershed shows that conditions in the Beauty Creek drainage are atypical in that peak flows are nearly indistinguishable from base flows at the monitoring location (Figure 3-10). Accurate representation of wetlands in the watershed and their effect on stream flow would likely require a linked watershed-receiving water model. Therefore, the decision was made to develop a calibrated model for a target watershed that captured the soil and land use characteristics of Beauty Creek, but was free of conditions that complicate simulation of rainfall-runoff responses.

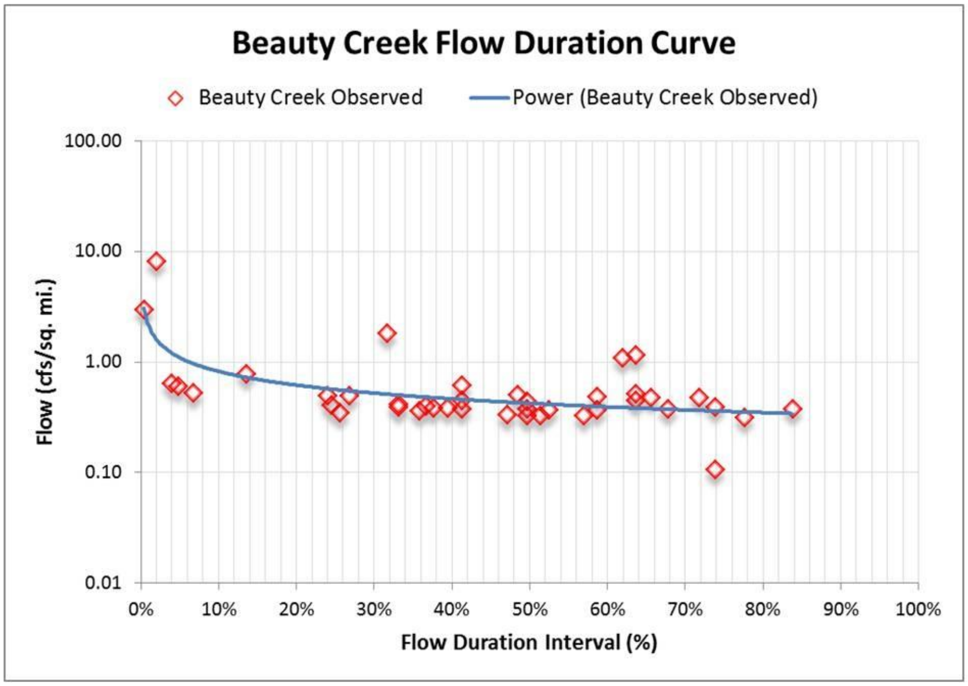


Figure 3-10. Beauty Creek flow duration curve.

Eight drainages in the Salt Creek watershed were investigated for their appropriateness as a target watershed for developing a calibrated watershed model of land use-soil combinations in Beauty Creek (Figure 3-11). The main criteria for selection were comparisons of flow duration curves of the eight drainages and for the Little Calumet River at Porter. The Little Calumet River USGS gage 04094000 is the closest long-term monitoring location to the study area. It has a drainage area of 64 square miles, which includes developed, rural, and forested land uses.

The large drainage area and mix of land uses suggest that the frequency of flows captured in the flow duration curve for this location can be generalized regionally for watersheds with mixed land cover and generally unaltered hydrology. In addition, because it is the only long-term continuous monitoring gage in the area, it is the only data source available for calibrating simulated hydrology. It is, therefore, critical that the target watershed show a similar flow duration response as the Little Calumet gage because these data will need to be extrapolated to the target watershed for comparisons of continuous stream flow as part of the model calibration process.

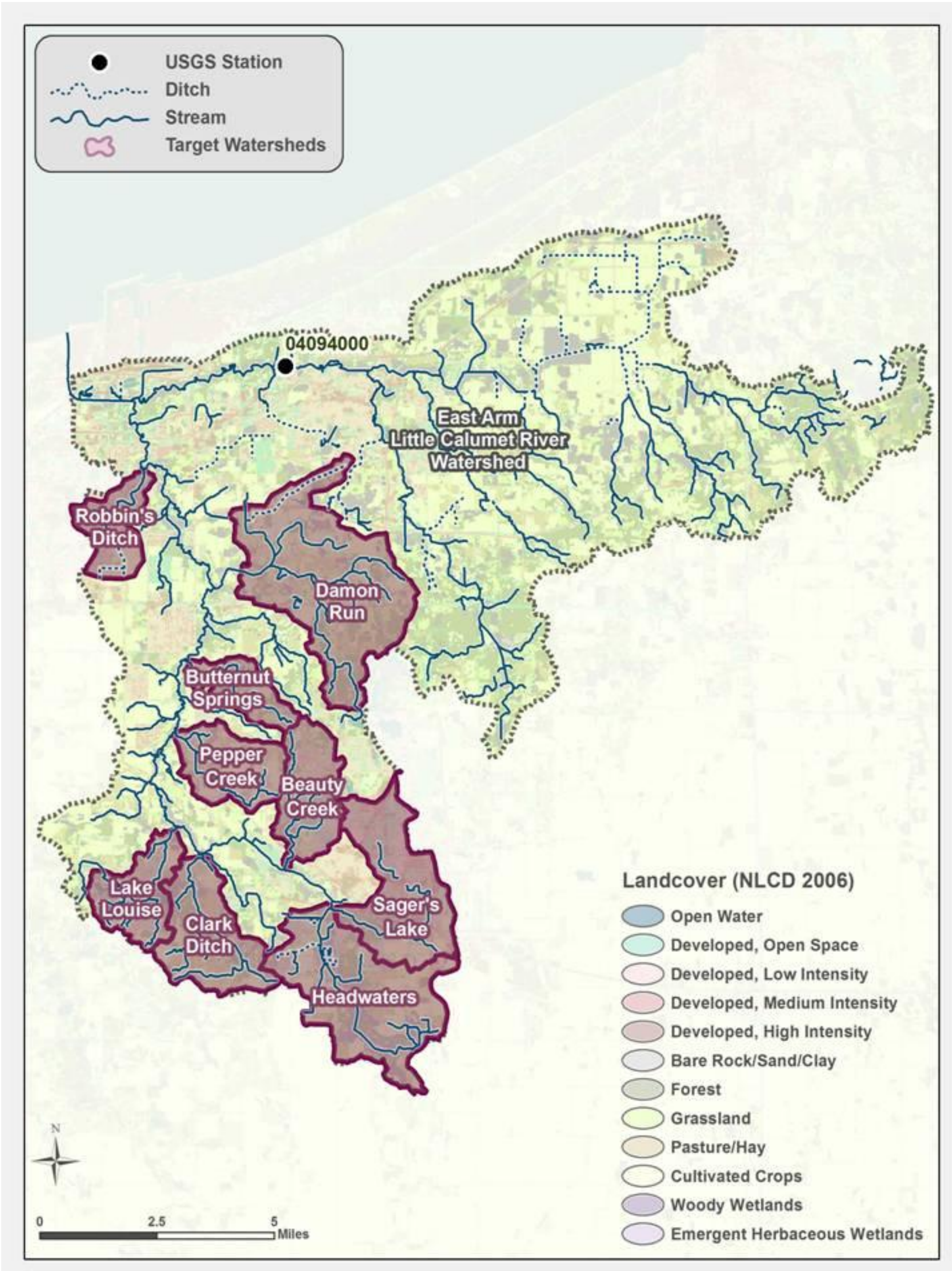


Figure 3-11. Beauty Creek target calibration catchments.

The Pepper Creek drainage was selected as the target watershed that best captured the land use-soil groupings of Beauty Creek and the general distribution of flows at USGS gage 040914000 (Figure 3-12). It is located directly adjacent to the Beauty Creek watershed and the land use-soil rainfall runoff response should closely reflect what occurs in Beauty Creek. The development of a calibrated model for the Pepper Creek drainage provides the necessary rainfall-runoff volumes that serve as a primary input to the *SUSTAIN* BMP model for select Beauty Creek catchments.

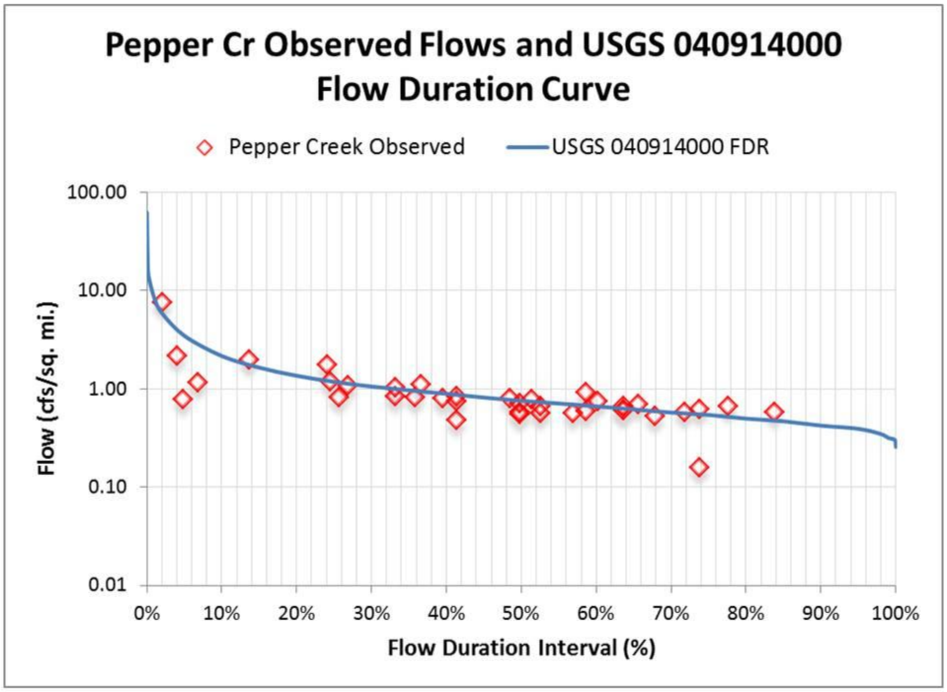


Figure 3-12. Comparison of Pepper Creek observed flows to Little Calumet duration curve.

Catchment Delineation. The Pepper Creek watershed was delineated into four catchments on the basis of the location of a monitoring site where field measurements of streamflow have been collected and land use. The three catchments located above the monitoring site range in size from 528 to 782 acres. A map of the catchments is presented in Figure 3-13. Catchments 2 and 4 contain significant areas of residential development, while catchment 3 is almost completely agricultural.

3.3.2 Hydrologic Response Units

One of the most significant technical challenges in the targeting and optimization process is connecting watershed runoff information to a BMP assessment framework. A technique being used in conjunction with rainfall-runoff modeling to address stormwater concerns is the use of Hydrologic Response Units (HRUs). Example applications of this method include project work in Vermont, the Charles River, and Los Angeles County. Dominant factors considered include land use, soil type, and slope.

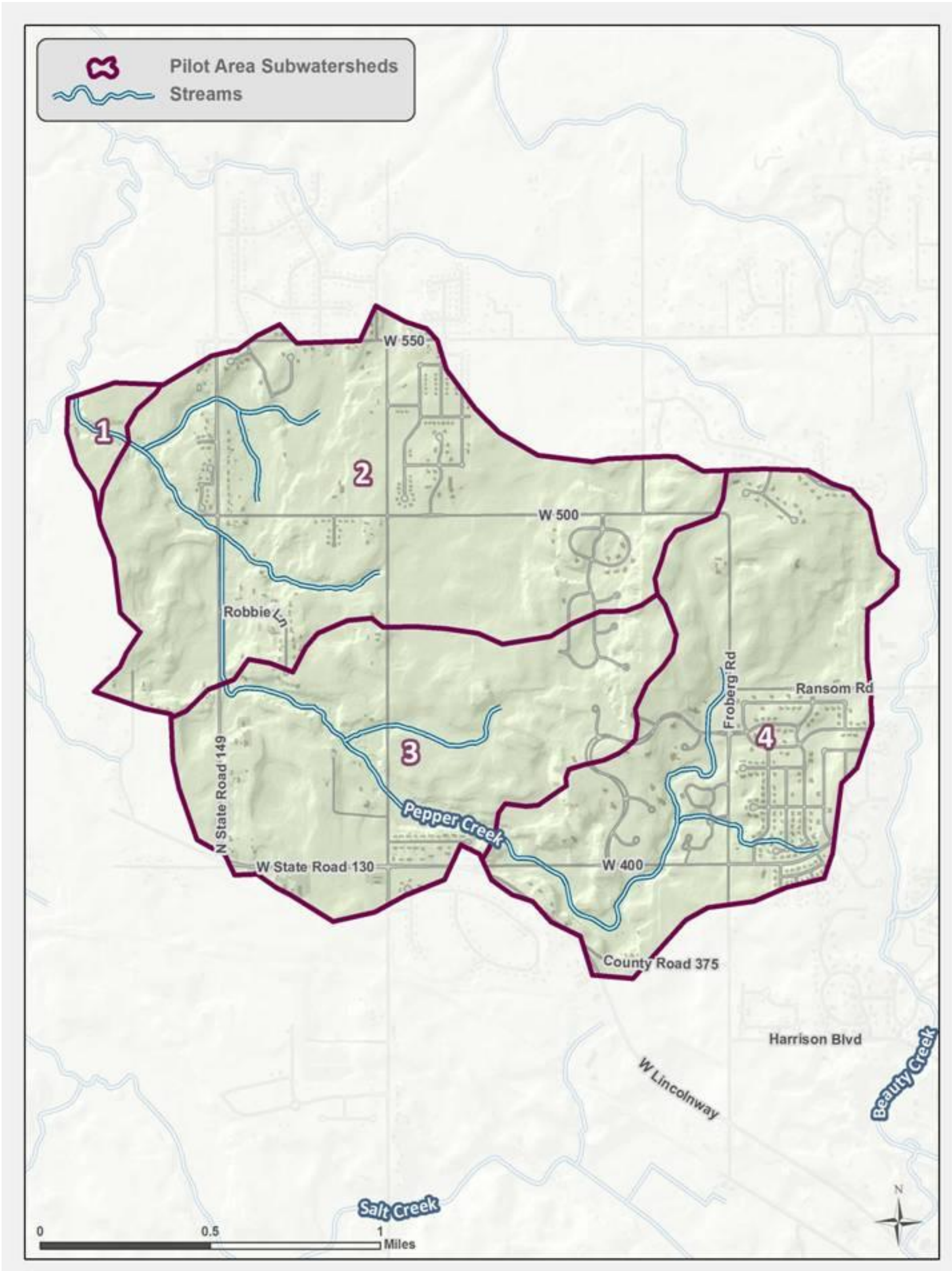


Figure 3-13. Pepper Creek catchments.

In a watershed model, land unit representation is sensitive to the features of the landscape that most affect hydrology. Important features include surface cover, soils, and slope. In urban settings, it is important to estimate the division of land use into pervious and impervious components. When hydrologic soil groups are not homogenous in a watershed, further subdividing pervious land cover according to hydrologic soil group can provide a higher degree of resolution. Slope might also be an important factor in some areas, particularly where it varies noticeably. In the case of the Pepper Creek watershed, the combination of hydrologic soil group, land cover, and slope were used to define HRUs for the study area. Calibration of the model establishes the hydrologic response of the HRUs. The target calibration is then transferred to Beauty Creek on the basis of the same composite HRUs.

Surface Slope. A 10-meter resolution digital elevation model (DEM) developed by USGS (2009) was used to evaluate the distribution of surface slope within the Beauty Creek and Pepper Creek study area. The DEM was processed using ESRI ArcMap 10 and the Spatial Analyst extension to derive a second raster representing percent slope throughout the study area.

Analysis of the distribution of slopes within the study area reveals that the values range between 0 and 76 percent (Figure 3-14). Approximately 94 percent of the area has slopes between zero and ten percent with a remaining five percent of the area having slopes between ten and 20 percent. This suggests that the area is generally flat, with some areas of moderate slopes. Considering that over 90 percent of the area has slopes less than ten percent, areas were classified as either below or above ten percent slope for the surface slope component of HRUs. A map showing percent slope is presented in Figure 3-15.

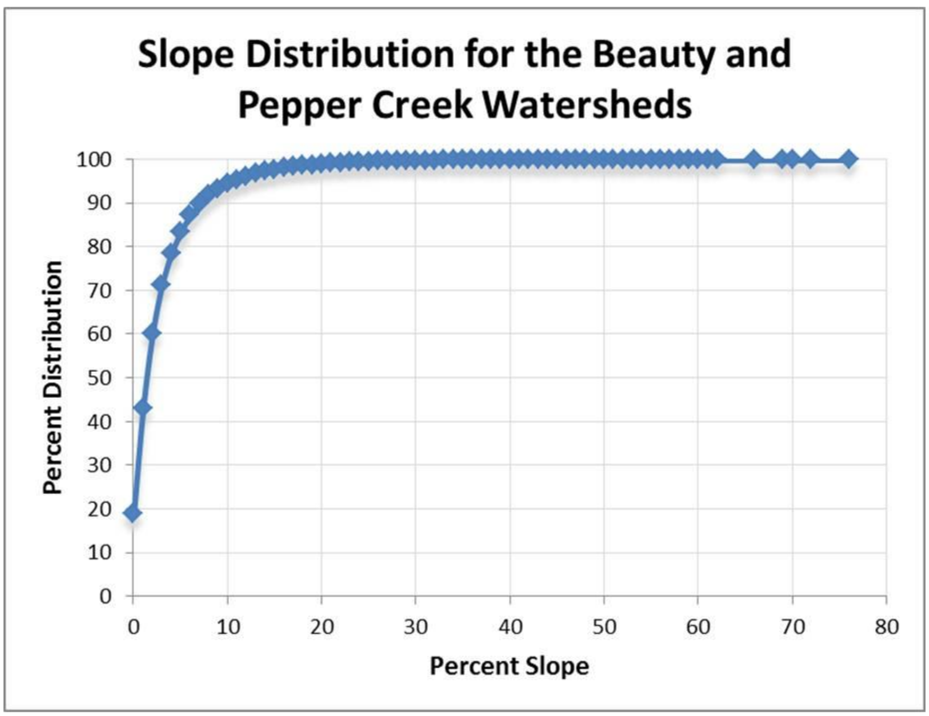


Figure 3-14. Distribution of slopes in Beauty and Pepper Creek subwatersheds.

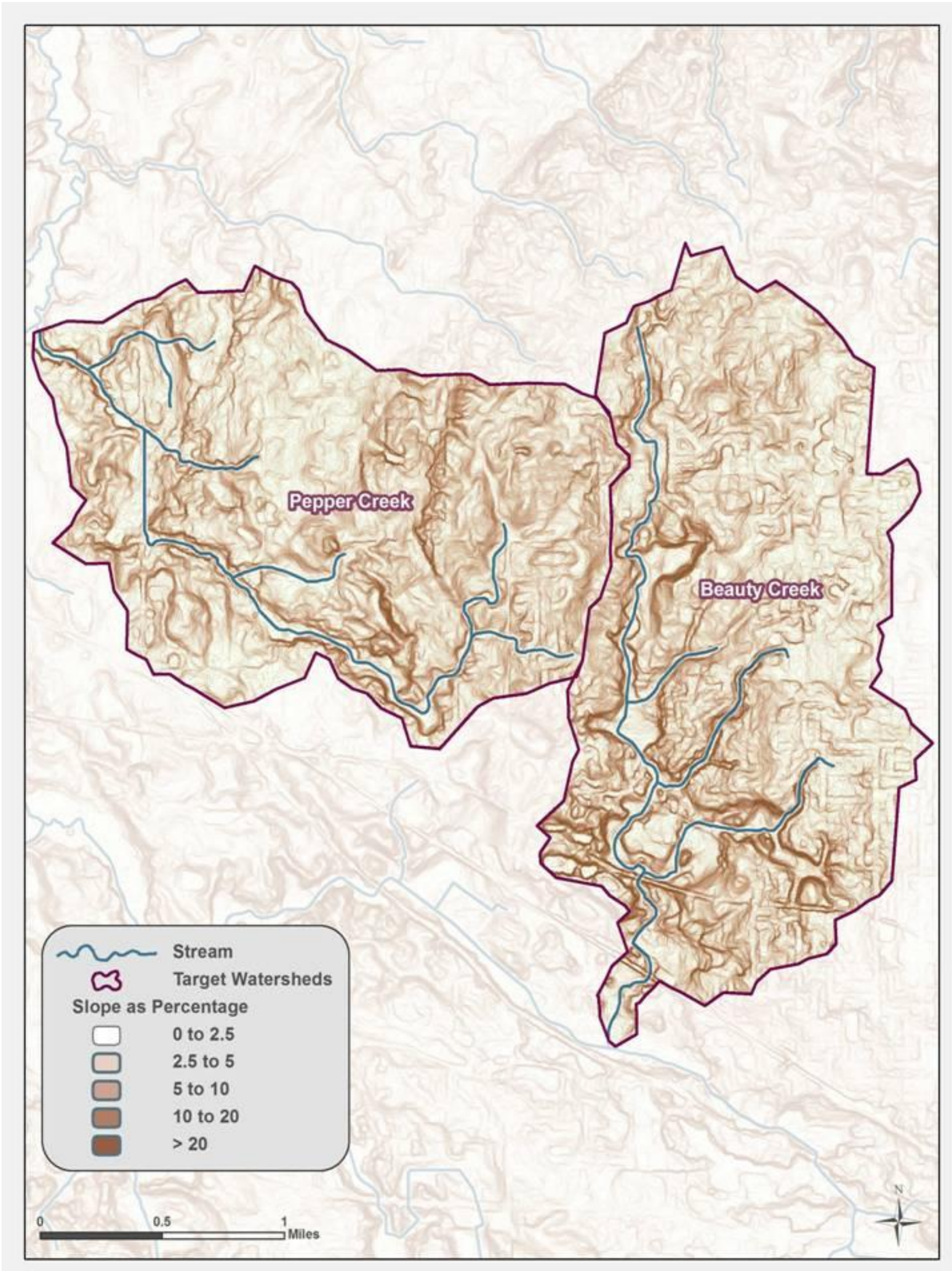


Figure 3-15. Beauty and Pepper Creek subwatershed slopes.

Impervious Surface Type. Estimates of land cover areas in the Beauty Creek and Pepper Creek watersheds were obtained from the 2006 Multi-Resolution Land Characteristics Consortium's National Land Cover Dataset (NLCD). The NLCD, developed and maintained by a partnership of federal agencies, is derived from satellite imagery classified into the land cover types according to reflective characteristics at 30-meter gridded intervals. A map showing the distribution of surface cover types for the study area is presented in Figure 3-16.

The watershed model requires that land cover categories be divided into separate pervious and impervious land units. This division was made for the appropriate developed land uses to represent impervious and pervious areas separately. The division was made on the basis of impervious percentage descriptions provided in the NLCD metadata as listed in Table 3-2.

Table 3-2. NLCD land cover categories

Land Cover ID	Land Cover Category	Percent Impervious
11	Open Water	0%
21	Developed, Open Space	10%
22	Developed, Low Intensity	35%
23	Developed, Medium Intensity	65%
24	Developed, High Intensity	90%
31	Barren Land (Rock/Sand/Clay)	0%
41	Deciduous Forest	0%
42	Evergreen Forest	0%
43	Mixed Forest	0%
52	Shrub/Scrub	0%
71	Grassland/Herbaceous	0%
81	Pasture/Hay	0%
82	Cultivated Crops	0%
90	Woody Wetlands	0%
95	Emergent Herbaceous Wetlands	0%

In addition to the NLCD, impervious surfaces have been classified as roads, parking lots, or building rooftops for developed areas in the Beauty Creek watershed. When the rainfall-runoff time series are transferred to the Beauty Creek *SUSTAIN* model, time-series for the impervious fraction of NLCD land uses will be assigned to those surfaces. Runoff from different types of impervious surface often requires different management practices.

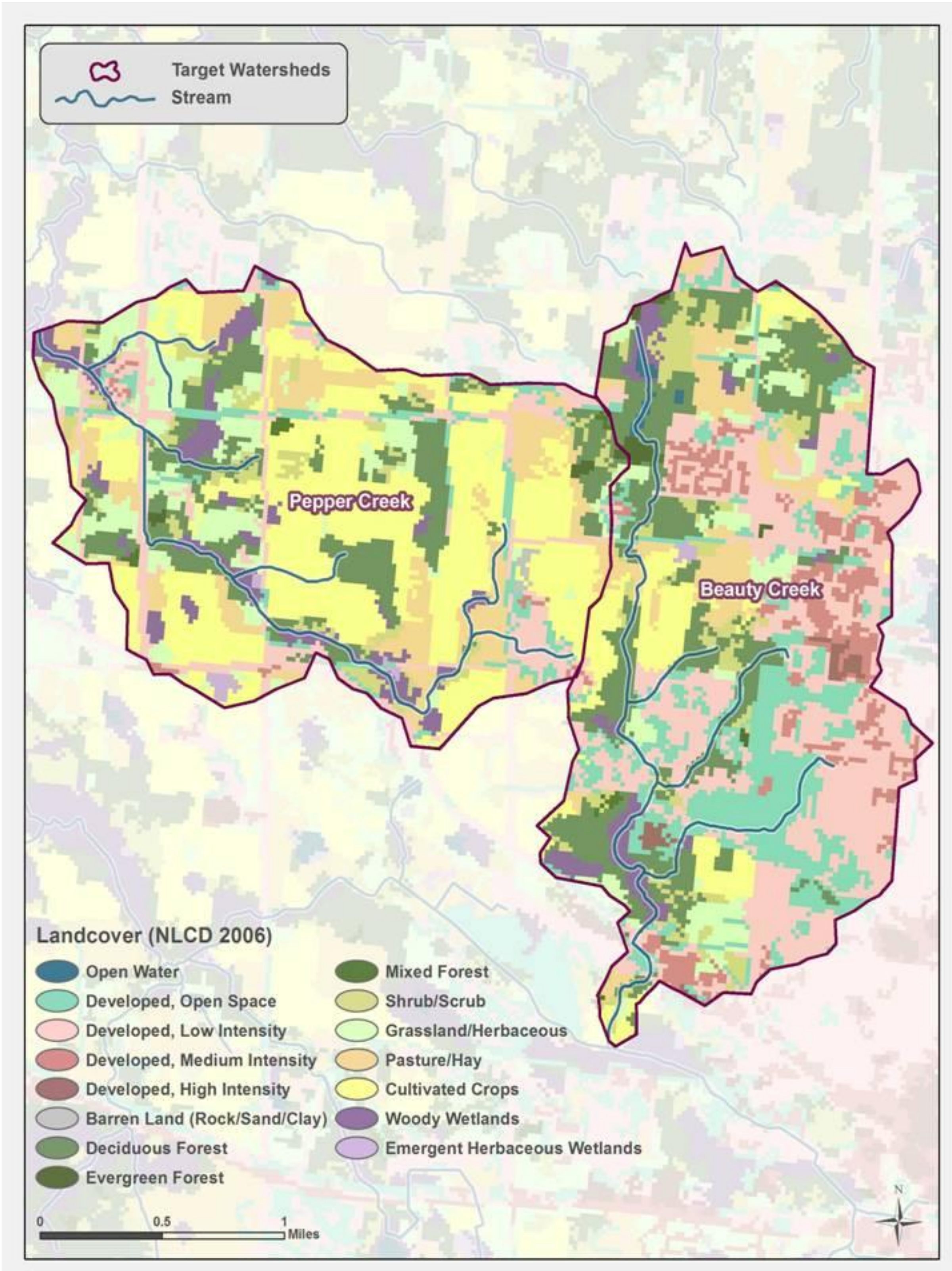


Figure 3-16. Beauty and Pepper Creek subwatershed land cover.

Hydrologic Soil Group. Geographic Information System data sets of hydrologic soil groups derived from the Soil Survey Geographic database (Natural Resources Conservation Service 2007) were used to identify the infiltration potential of soils. Hydrologic soil groups are used to classify the infiltration capacity of soils by rating them as either class A, B, C or D; A has the highest and D the lowest infiltration potential. Unknown and predominately urban soil types were also classified according to the lettered infiltration scheme according descriptions of the soil fill and consideration of the compaction and disturbance that typically occurs during grading and construction. A map showing the hydrologic soil groups for the Beauty Creek and Pepper Creek watersheds is presented in Figure 3-17. In general, the two watersheds show moderate to slow infiltration, with large areas of B and C soils. There are also significant areas of D soils, which indicate a high runoff potential for these pervious areas.

Beauty Creek Model HRUs. An overlay of slope, soil, and land cover was performed using the datasets described. This overlay resulted in a distribution of forty-one unique HRU categories that capture the physical texture of the study watersheds (Table 3-3). The components of an HRU are hyphenated and correspond in order to the NLCD land cover category, slope (Low Slope ≤ ten percent; Moderate Slope > ten percent), and hydrologic soil group. Pervious portions of Developed, Open Space and Developed, Low Intensity were grouped into a Developed Low HRU (HRU IDs 210–220). Pervious segments of Developed, Medium and High Intensity were grouped into a Developed High HRU (HRU IDs 310–320). Both HRUs have an impervious component (HRU IDs 1000 and 2000). The hydrologic soil group of developed land cover categories was considered negligible due to the effects of compaction and disturbance on urban fill soils. Forested, shrub and grass land covers were grouped.

Table 3-3. HRUs for the Beauty and Pepper Creek subwatersheds

HRU ID	HRU Description	HRU ID	HRU Description
210	Developed Low, Pervious-Low Slope	611	Pasture_LowSlope_A
220	Developed Low, Pervious-Moderate Slope	612	Pasture_LowSlope_B
310	Developed High, Pervious-Low Slope	613	Pasture_LowSlope_C
320	Developed High, Pervious-Moderate Slope	614	Pasture-Low Slope-D
411	Forest-Low Slope-A	621	Pasture-Moderate Slope-A
412	Forest-Low Slope-B	622	Pasture-Moderate Slope-B
413	Forest-Low Slope-C	623	Pasture-Moderate Slope-C
414	Forest-Low Slope-D	624	Pasture-Moderate Slope-D
421	Forest-Moderate Slope-A	711	Crop-Low Slope-A
422	Forest-Moderate Slope-B	712	Crop-Low Slope-B
423	Forest-Moderate Slope-C	713	Crop-Low Slope-C
424	Forest-Moderate Slope-D	714	Crop-Low Slope-D
511	Shrub/Grass-Low Slope-A	721	Crop-Moderate Slope-A
512	Shrub/Grass-Low Slope-B	722	Crop-Moderate Slope-B
513	Shrub/Grass-Low Slope-C	723	Crop-Moderate Slope-C
514	Shrub/Grass-Low Slope-D	724	Crop-Moderate Slope-D
521	Shrub/Grass-Moderate Slope-A	800	Wetland
522	Shrub/Grass-Moderate Slope-B	913	Barren-Low Slope-C
523	Shrub/Grass-Moderate Slope-C	923	Barren-Moderate Slope-C
524	Shrub/Grass-Moderate Slope-D	1000	Developed Low, Impervious
		2000	Developed High, Impervious

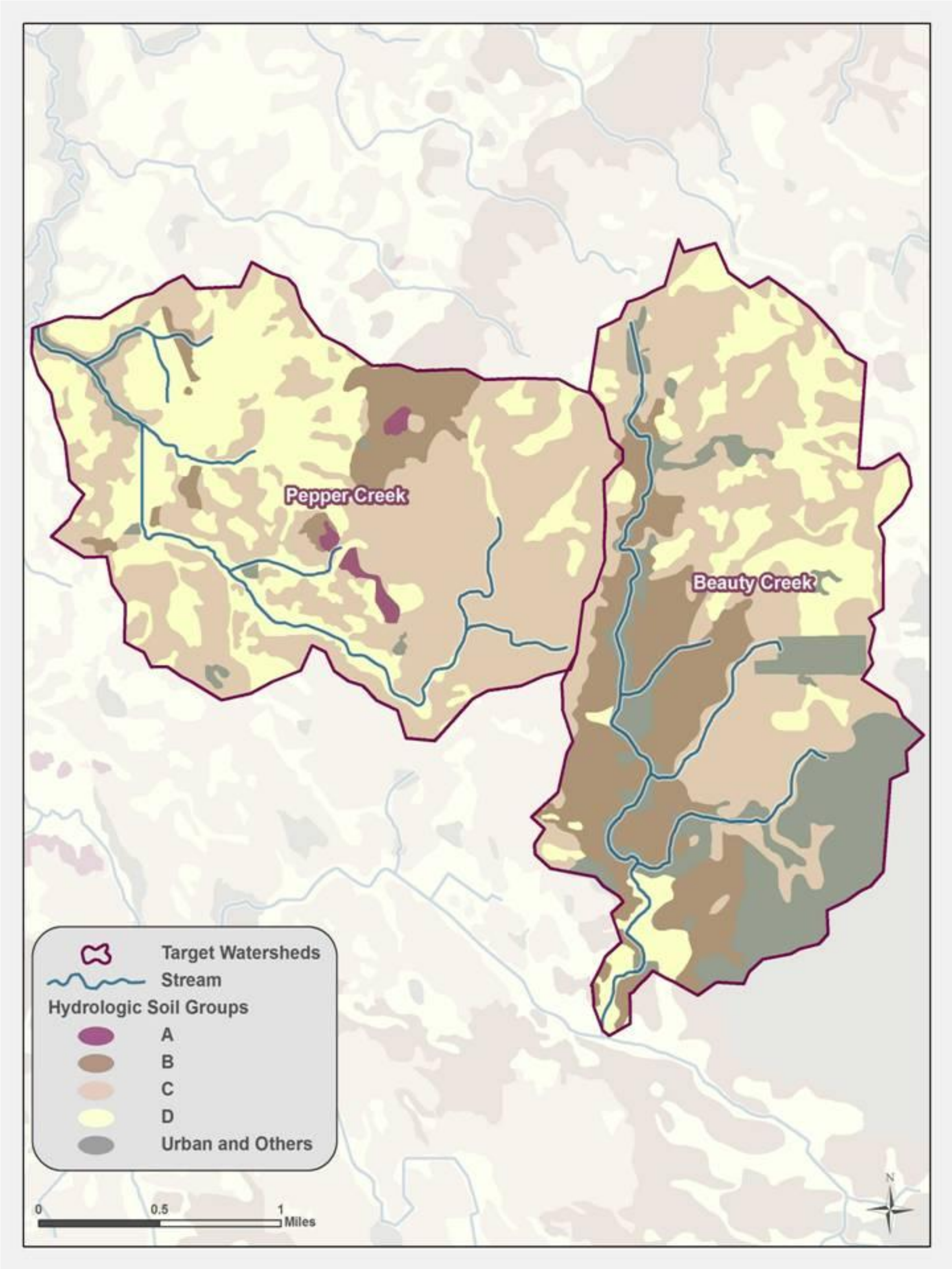


Figure 3-17. Hydrologic soil classifications for the Beauty and Pepper Creek subwatersheds.

3.3.3 *Rainfall – Runoff Time Series*

A rainfall-runoff time series was generated for each HRU. The Loading Simulation Program C++ (LSPC) was used to provide initial estimates. LSPC is a re-coded version of the Hydrologic Simulation Program FORTRAN (HSPF) watershed model. Calibration consists of the process of adjusting model parameters to provide a match to observed conditions. Calibration is necessary because of the semi-empirical nature of water quality models. Although these models are formulated from mass balance principles, most of the kinetic descriptions in the models are empirically derived. These empirical derivations contain a number of coefficients that are usually determined by calibration to data collected in the waterbody of interest.

Currently, the only flow data collected in the target Pepper Creek watershed are 41 instantaneous flow samples collected at the base of the watershed. To develop a robust calibration of the watershed model, continuous daily average stream flow data from USGS gage 04094000 were scaled to the Pepper Creek watershed based on the ratio of the contributing watershed area. The scaled daily data will allow for comparisons to daily simulated stream flow.

Multiple methods of scaling were investigated including linear regression based on the available instantaneous flows, but the ratio method produced a time-series that best matched model output compiled using default calibration parameters. Moreover, a comparison of scaled daily stream flow derived using the ratio and linear regression methods shows that the two methods produce very similar results making the datasets largely interchangeable. This comparison of average daily stream flow estimated for the same day is shown in Figure 3-18.

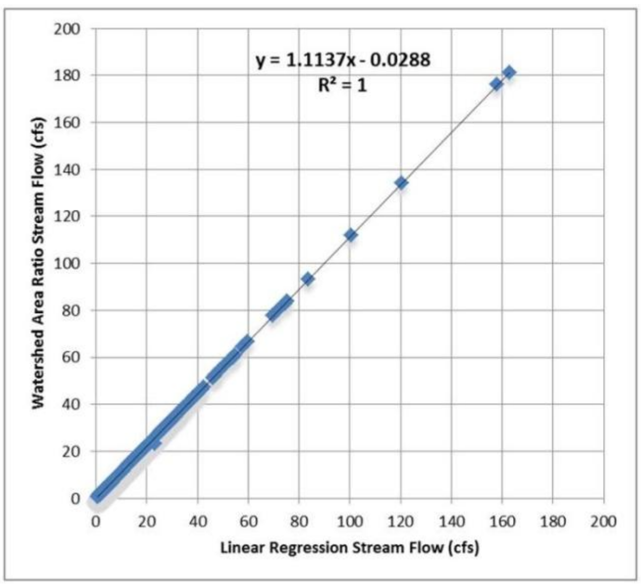


Figure 3-18. Comparison of stream flow estimates *(watershed area vs. linear regression)*.

<u>*Calibration Process*</u>. Calibration tunes the model to represent conditions appropriate to the waterbody and watershed under study. During hydrology calibration, land segment hydrology parameters are adjusted iteratively to achieve agreement between simulated and observed stream flows at specified locations. Agreement between observed and simulated stream flow data is first evaluated on an annual and seasonal basis using quantitative and qualitative measures. Specifically, annual water balance, groundwater volumes and recession rates, and surface runoff and interflow volumes and timing are evaluated, along with composite comparisons (e.g., average monthly stream flow values over the period of record).

Hydrologic predictions from the model are most sensitive to external forcing by precipitation, followed by potential evapotranspiration (PET). These weather inputs are typically not adjusted during calibration. Within the model, the annual water balance is usually most sensitive to the specification of the lower zone nominal storage (LZSN) and the lower zone evapotranspiration factor (LZETP), both of which control the amount of water lost to evapotranspiration. The distribution of runoff between storm and non-storm conditions is usually most sensitive to the infiltration index (INFILT) and groundwater recession rate (AGWRC).

The hydrologic model will be calibrated by first adjusting model parameters until the simulated and observed annual and seasonal water budgets are in good agreement. Then, the intensity and arrival time of individual events is calibrated. This iterative process is repeated until the simulated results closely represent the system and reproduce observed flow patterns and magnitudes. Sensitivity analyses for model input parameters can help guide this effort. Below is a more detailed description of the steps in this iterative process.

- *Annual water balance.* In this step, the total average annual simulated flow volume is compared with the observed data. The input precipitation and evaporation data set, along with the calibration parameters LZSN, LZETP, and INFILT are the main factors influencing the annual water balance. Other factors include anthropogenic water inputs and outputs, and groundwater exchanges.
- *Low flow/high flow distribution.* The low flows are usually matched first by adjusting the INFILT and AGWRC parameters. Low flows are also dependent on the accurate representation of point source discharges, water withdrawals, and groundwater exchanges.
- *Seasonal adjustments.* Adjustments related to seasonal differences can be made to CEPSC (interception storage capacity; vegetal interception), LZETP, and upper zone nominal storage (UZSN). Updates to KVARY (variable groundwater recession) and fraction of PET satisfied from base flow (BASETP) are also possible.
- *Storm peaks and hydrograph shape.* Simulated storm event peaks are compared to available storm hydrograph and storm peak data for selected storms. The stormflow is largely dependent on surface runoff and interflow volumes and timing. Changes can be made to the INFILT, UZSN, INTFW (interflow parameter), IRC (interflow recession), and the overland flow parameters for length, Manning's n (roughness), and slope (LSUR, NSUR, and SLSUR), among other upland parameters. Storm hydrographs are also sensitive to the reach FTables, which may need to be re-evaluated to reproduce observed hydrographs.

Various parameters such as INFILT are likely to be adjusted in more than one of the steps described above. Therefore, all components must be rechecked for consistency at the end of the hydrologic calibration process.

Calibration Results. The watershed model of the Pepper Creek watershed was calibrated for the time period 1991–2004. Though weather data have been compiled through 2010, after 2004 greater than 50 percent of precipitation data per year were estimated based on near-bye precipitation station because data at the primary station were missing (Figure 3-19*)*. Therefore, the calibration was based on years for which the best weather data are available.

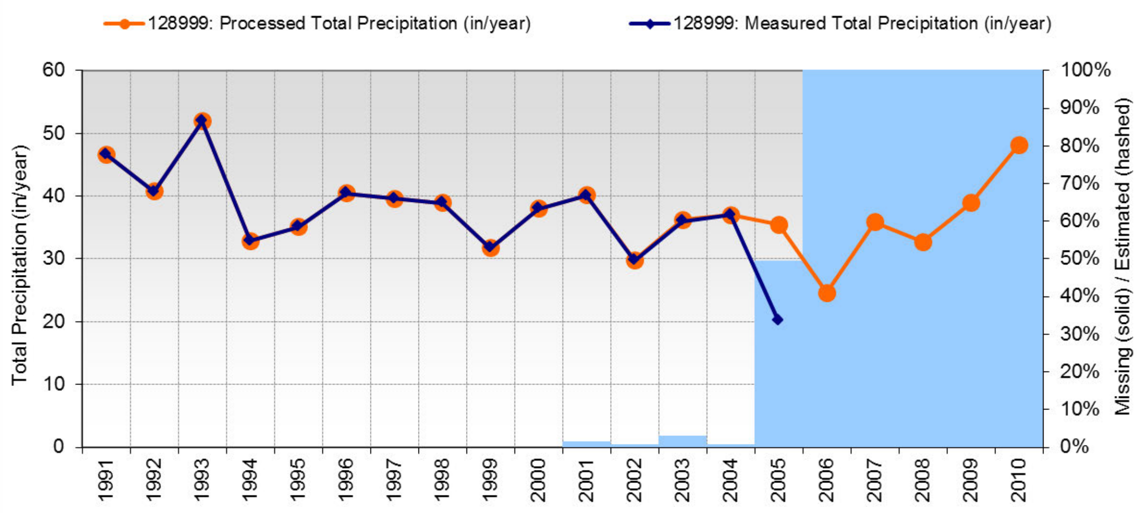


Figure 3-19. Comparison of Pepper Creek modeled versus observed monthly average flows.

A comparison of simulated and observed (scaled) average monthly stream flow are presented by month in Figure 3-19, and aggregated for the entire calibration period in Figure 3-20. In general, average monthly volumes are predicted well by the watershed model. Figure 3-20 shows that modeled and observed seasonal median stream flow are nearly identical, though modeled low and high flows show much more variability, particularly in the spring and summer. This trend could be an artifact of using the scaled observed data for comparison, where the large Calumet drainage would be much less flashy than stream flow in a smaller watershed such as Pepper Creek.

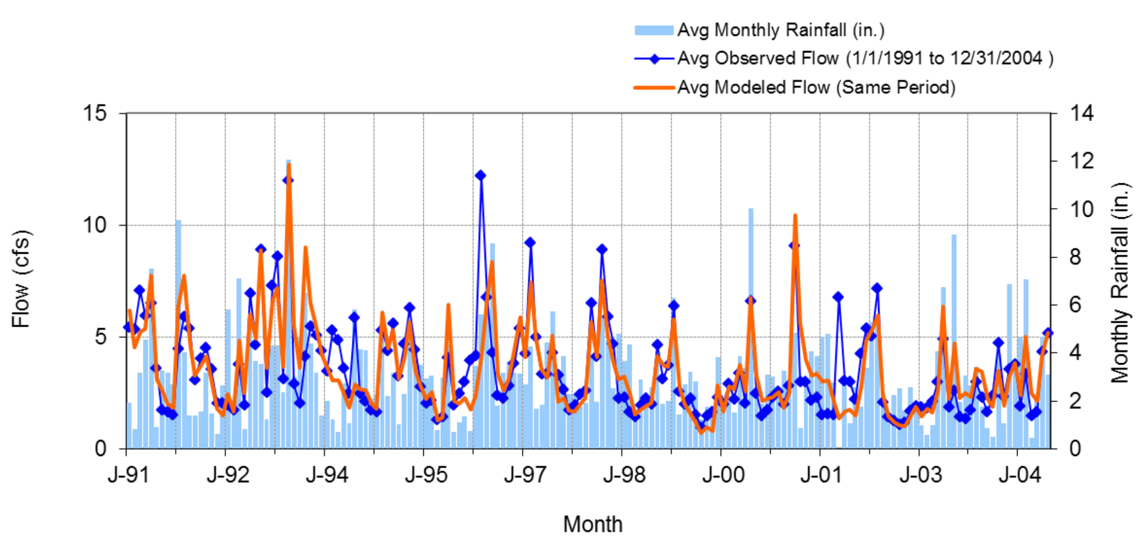
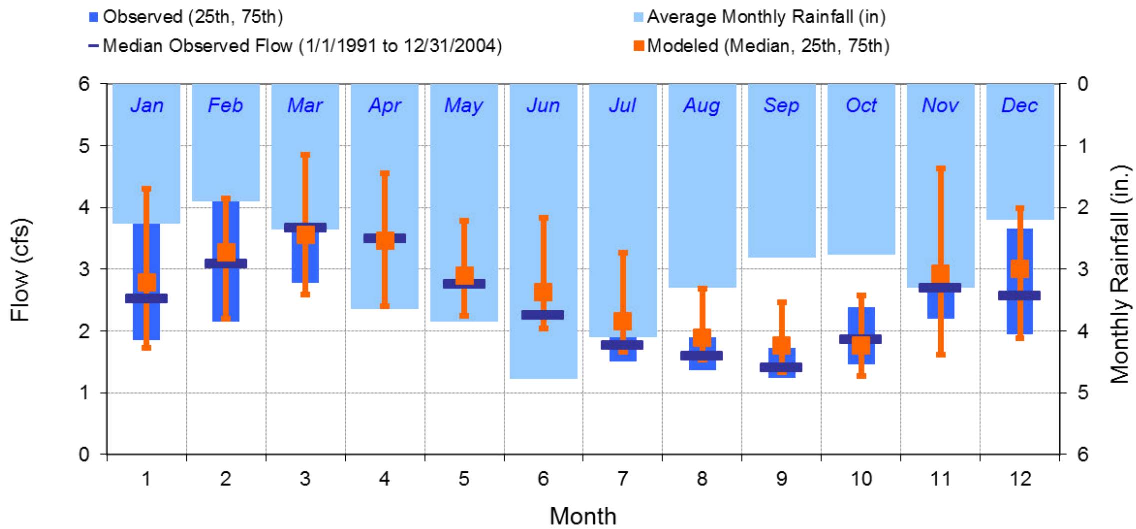


Figure 3-20. Comparison of Pepper Creek modeled versus observed monthly average flows.



As a final check of the model calibration a flow duration curve was generated for the modeled Pepper Creek stream flow. The observed instantaneous stream flow data were superimposed on flow duration curve to verify that the distribution of simulated flows was comparable distribution of observed flows. In general, simulated stream flow matches the distribution of observed flows well.

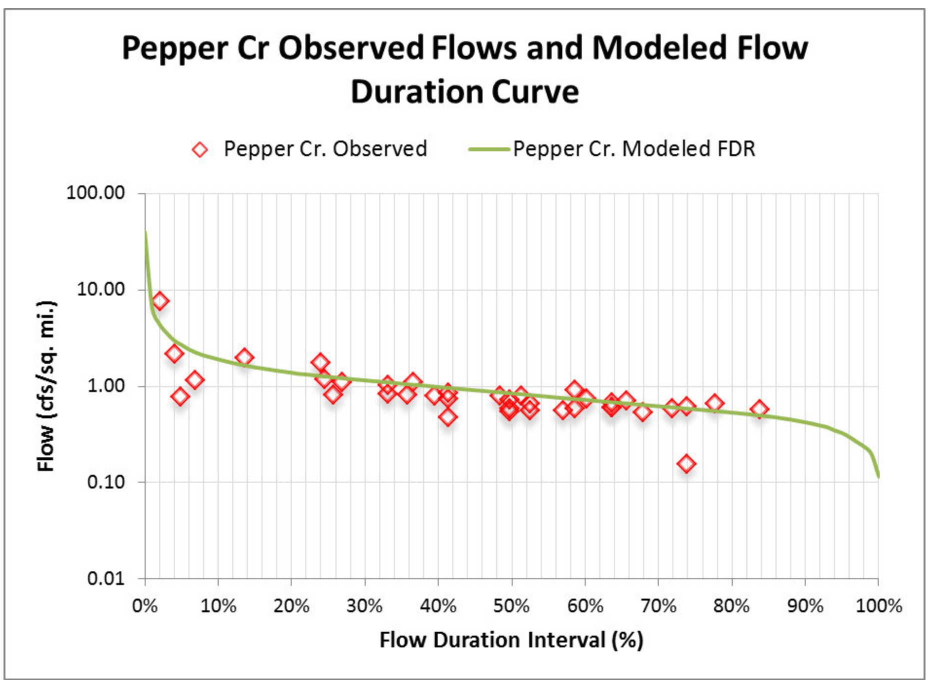


Figure 3-21. Comparison of Pepper Creek observed flows to modeled flow duration curve.

4. Identify Potential BMPs

Identifying the appropriate suite of BMPs for analysis in *SUSTAIN* requires an understanding of the watershed, pollutant sources, available treatment area, and feasibility of BMP construction. For the Beauty Creek pilot area, a residential area evaluation was conducted to determine if there were differences in the residential area that would warrant a unique set of BMPs. The types of BMPs that are feasible for the Beauty Creek pilot area were then selected.

Examples of the stormwater management practices that can be assessed with *SUSTAIN* include bioretention, rain barrels, cisterns, detention ponds, infiltration trenches, vegetative swales, porous pavement, and green roofs. However, not all BMPs are equally suitable to all site conditions and performance goals across watersheds. Consequently, several important site-specific factors were considered when identifying those BMPs to include in the project analysis. This section presents a brief overview describing the general representation of practices within *SUSTAIN*. An assessment of BMP opportunities within the test area is provided following that discussion.

The BMP module within *SUSTAIN* is designed to provide a process-based simulation of flow and pollutant transport routing for a wide range of structural practices. The BMP module performs the following hydrologic processes to reduce land runoff volume and attenuate peak flows: evaporation of standing surface water, infiltration of ponded water into the soil media, deep percolation of infiltrated water into groundwater, and outflow through weir or orifice control structures. A simplified schematic of the BMP simulation process is included in the *SUSTAIN* manual and is shown in Figure 4-1.

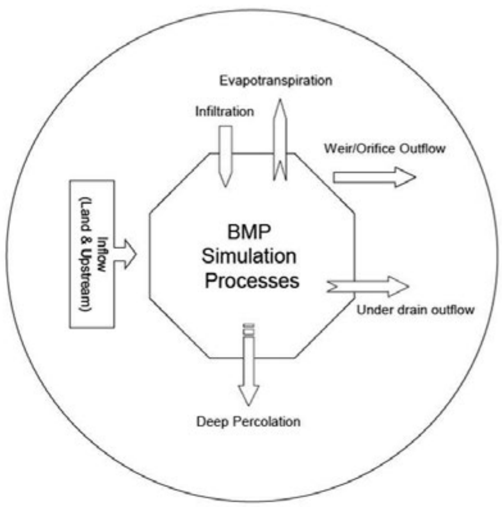


Figure 4-1. BMP simulation processes.

Urban stormwater BMPs in *SUSTAIN* are simulated according to a set of design specifications using a unit-process parameter-based approach (Figure 4-2). This has many advantages over most other modeling tools, which simply assign a single percent effectiveness value to each type of practice. Overall BMP performance in *SUSTAIN* is a function of its physical configuration, storm size and associated runoff intensity and volume, and moisture conditions in the BMP.

A general estimate of BMP performance can be developed for each practice being considered. One way to view this information is in in terms of sizing. Sizing of BMPs is typically focused on capturing a certain depth of runoff (e.g., WQv). Curves can be developed that show the performance of a BMP over a long-term period (rather than as a single storm or design storm event. This is an important aspect of the BMP opportunity assessment. Inherently, assumptions must be made when transitioning from a location specific analysis (e.g., site-scale) to an evaluation of larger areas, such as the neighborhood- or watershed-scale (Figure 4-3).

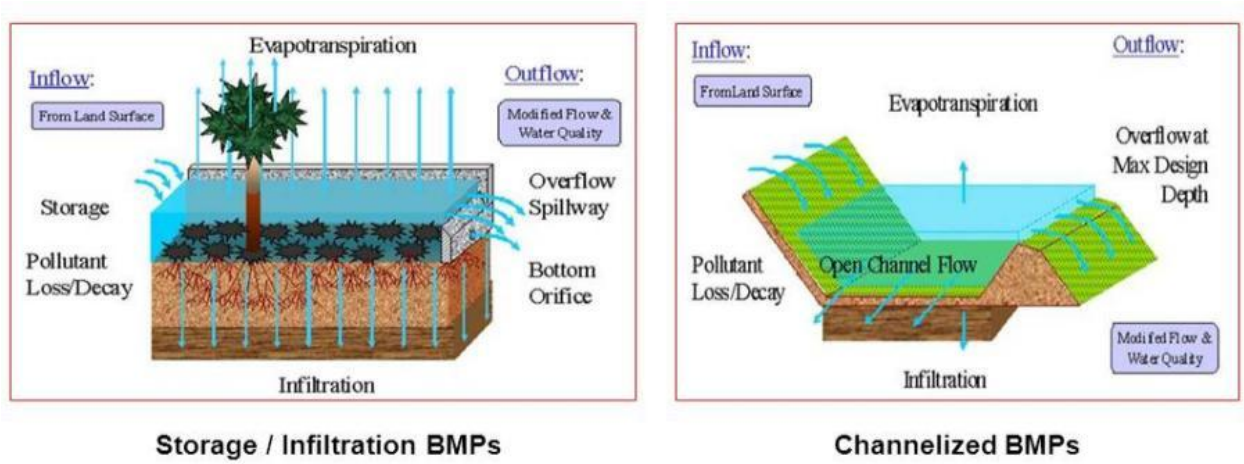


Figure 4-2. Major processes included in BMPs.

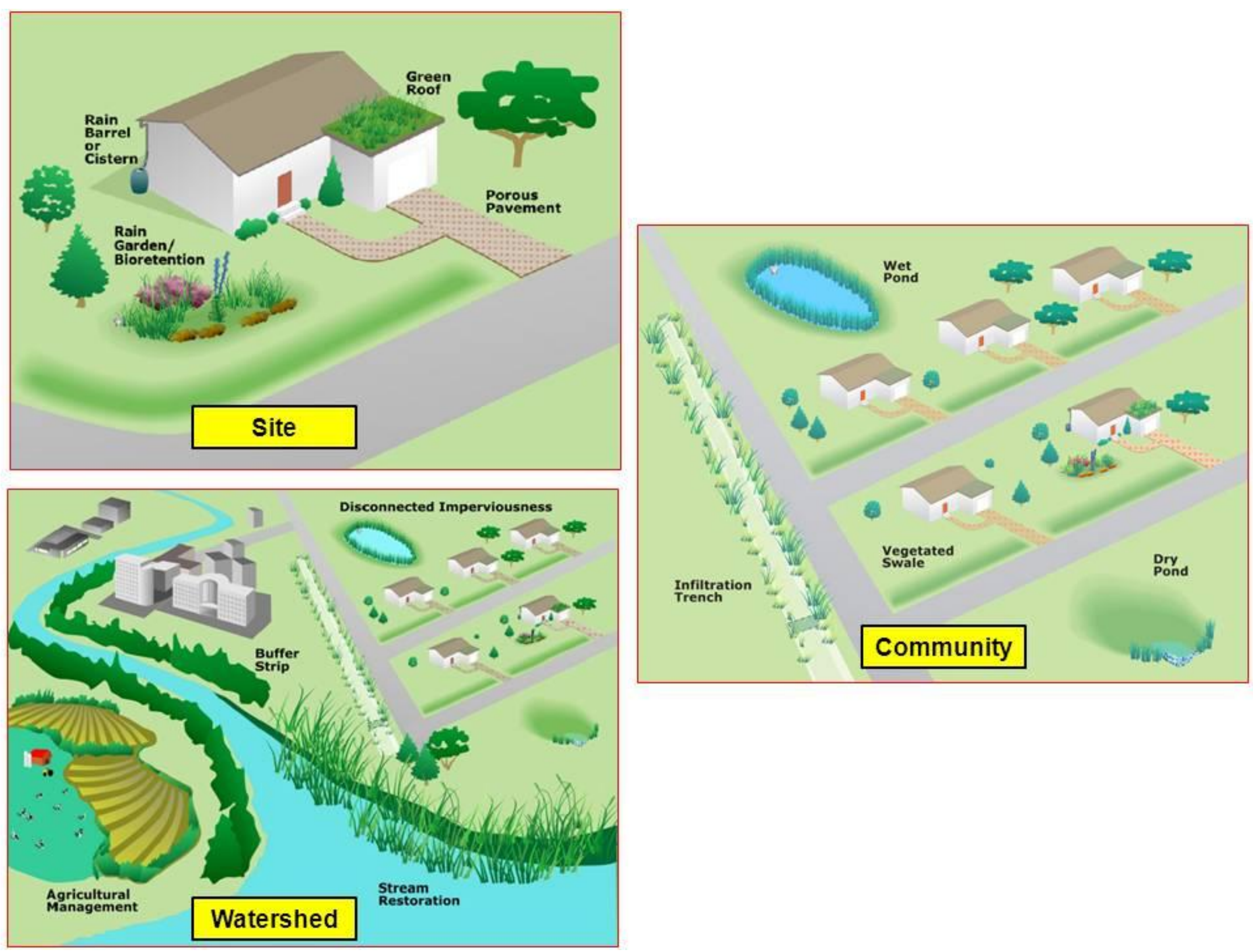


Figure 4-3. BMP assessment scales.

Figure 4-4 shows an example performance curve for a BMP of interest in this pilot effort: bioretention. One benefit of developing these curves is that they illustrate the sensitivity of BMP performance to the range of key variable (e.g., infiltration rates, storage depth). The curves also provide a way to quantify uncertainty regarding assumptions. In addition, the performance curves highlight those design parameters that are most important when developing specifications for implementation projects. Several example key design parameters that can be varied in *SUSTAIN* for bioretention are listed in Table 4-1. Finally, the curves can help guide decisions where cost trade-offs are involved (e.g., size of area to treat, amount of amendment material to promote greater infiltration, underdrain system design).

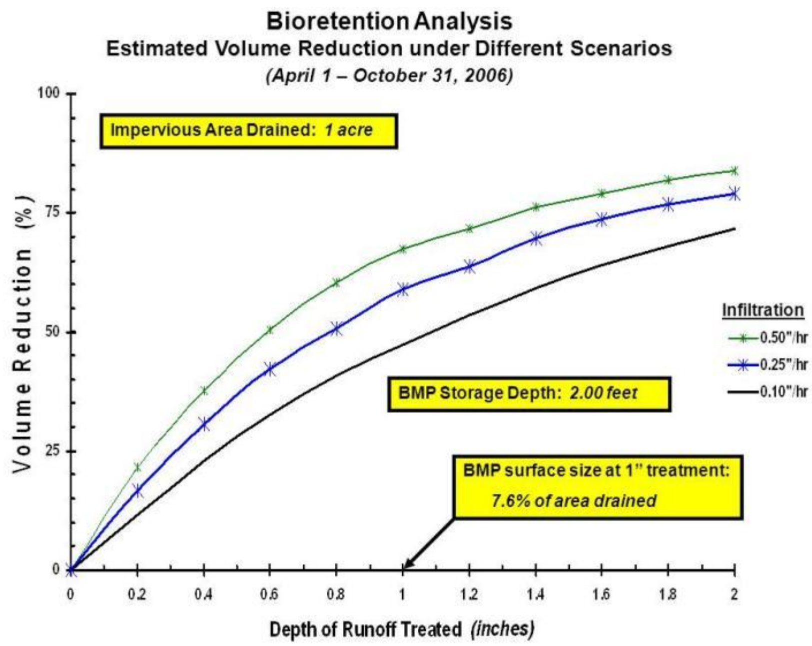


Figure 4-4. General BMP performance curve -- bioretention.

Table 4-1. Example key BMP design parameters -- bioretention

Dimensions	
• Length *(feet)* • Width *(feet)* • Ponding depth defined through one of following options: ✓ Orifice height *(feet)* ✓ Weir height *(feet)*	• Design drainage area *(acre)*
Substrate Properties	
• Depth of soil *(feet)* • Soil porosity *(0 - 1)* • Soil field capacity • Underdrain structure *(if applicable)* o Storage depth *(feet)* o Media void fraction *(0 - 1)*	• Soil wilting point • Vegetative parameter A • Soil layer infiltration *(inches / hour)* o Background infiltration *(inches / hour)*

The selected pilot area, along with much of the Beauty Creek watershed, contains low permeability soils. Because of this known natural constraint and the desire to optimize to volume reduction, BMPs which promote significant infiltration including infiltration basins and trenches were not considered as part of the suite of applicable practices. There are several large tracts of open space within the pilot area, so detention ponding is included in the suite of applicable BMPs. Based on the available technologies contained within the BMP assessment model, the following best management practices were considered for the Beauty Creek pilot area:

- Bioretention (e.g., rain gardens, bioswale, bioretention facilities)
- Porous pavement
- Rain water harvesting (e.g., rain barrels)
- Green roofs
- Detention ponds

Each of the BMPs was evaluated for applicability in the watershed on the basis of a review of aerial imagery, impervious cover data, and land use datasets. Candidate locations were selected according to available land area and proximity to sources of runoff and pollutants.

The assessment of BMP opportunities also involved analyzing various combinations of practices (i.e., treatment trains). Using a treatment train approach, stormwater management begins with simple methods that minimize the amount of runoff that occurs from a site. Typically those practices involve either on-site interception (e.g., rain barrels) or on-site treatment (e.g., bioretention, porous pavement).

The following sections provide a description of each BMP and the considerations made during the applicability analysis. Modeled design specifications for each practice are described in Section 5.

4.1 Bioretention

Three types of bioretention practices were included in the BMP opportunities assessment: (1) rain garden; (2) bioswale between sidewalks and curbs; and (3) bioretention facility. Bioretention is modeled as a consolidated practice, which means that specific locations are not identified. However, within each discrete drainage area boundary, a template was designed and applied to treat the relevant associated land sources upstream. With that approach, the fraction of area treated or untreated was also defined so that the upper bound of BMP size reflects the maximum potential drainage area that could be captured by the practice. BMP sizing and treatment distribution are the optimization variables of concern.

4.1.1 Rain Garden

Rain garden areas are assumed to be located in front yards of residential areas and are designed to serve the overflow from rain barrels and runoff from the surrounding area (75 percent of the front yard) in residential areas A, C, and D. Driveways are routed to rain gardens through a trench drain at the bottom of the driveway, thereby capturing this impervious area prior to discharging into the road. A total of 16.4 acres (8.8 impervious and 7.7 pervious acres) could be treated by rain gardens.

Rain gardens are assumed to be constructed and maintained by the homeowner with little costs associated with design. A two foot soil amendment is assumed with no underdrain. Front yard size was considered when setting the upper limit on the area of the bioretention practices (150 square feet). Based on typical willingness of homeowners, it is assumed that a maximum of 30 percent of homes could be served by rain gardens in combination with a rain barrel within Residential Areas A and C as well as 20 percent of the homes in Residential Area D.

4.1.2 Bioswale

Bioswales are linear features that are designed to provide offline retention for road runoff and surrounding areas. Potential locations for bioswales in residential areas were identified through aerial imagery analysis and spatial data. It is assumed that bioswales could be installed along 60 percent of the roadways in Residential Area B where sufficient width of green space exists between the curb and sidewalk. Bioswales are assumed to be up to eight feet in width encompassing up to 0.7 acres of the watershed with six inches of ponded depth. A 48 inch soil amendment is assumed with a free flowing underdrain. The practices are represented in the model similarly to rain gardens and are assumed to treat runoff associated with the road as well as 80 percent of the front yards, driveways, and front half of roofs, resulting in up to 4.5 acres of impervious and 1.4 acres of pervious surfaces in residential area B being treated.

Campbell Street includes 8 to 14 feet of green space between the curb and sidewalk, and therefore bioswales are modeled along both sides of this street resulting in an additional 1.3 acres of potential bioswales treating 5.4 acres of impervious area. No additional pervious area runoff is assumed to reach these bioswales.

4.1.3 Bioretention Facilities

Bioretention facilities are typically larger rain gardens with underdrains, and in this case, are designed to capture and retain runoff from all of Residential Area A. Because they have underdrains, bioretention also provides filtration benefit as stormwater passes through the soil media. Potential locations for bioretention were identified adjacent to catch basin inlets at 30 locations. Catch basin inlets already represent low lying areas where runoff travels, making them effective candidate locations for intercepting runoff.

Bioretention facilities are sized according to the available land area adjacent to the roads and are assumed to be up to 300 square feet in size, encompassing up to 0.2 acres of the watershed. Bioretention facilities are designed for six inches of ponded depth, with 48 inches of plant and soil media, and include free-flow perforated pipe underdrains set four below the bottom of the basin. The contributing drainage area to bioretention facilities includes the entire residential area A consisting of 12.2 acres of impervious area and 37.3 acres of pervious area.

4.2 Porous Pavement

Porous pavement was assumed to be applicable throughout the pilot residential areas. There are several different types of pavement present within the pilot area, including sidewalks, roads, alleys, and parking lots. Driveways were not considered for installation of porous pavement. Table 4-2 summarizes the different types of roadways throughout the pilot area, including non-residential areas. Campbell Street is wider than the typical roads in the area with an average width of 40 feet with an associated 5.4 acres of imperviousness. Therefore, it is evaluated separately from the other residential roadways.

Table 4-2. Pavement summary

Streets	**Length** (ft)	**Average width** (ft)	**Area** (acres)
Roads (excluding Campbell Street)	56,115	32	41.2
Campbell Street	5,865	40	5.4
Alleys	3,643	10	0.8
Parking Lots			18.8
Sidewalks			10.2
Total			**71.3**

Residential street widths vary across the pilot area *(*Table 4-3*)*. The widths of residential streets were also evaluated to determine if they can be reduced, thus reducing imperviousness and providing additional front yard green space. Reduced street width will also decrease motorist speeds within the residential areas. Costs are not included for impervious surface reduction, as it is assumed that it would occur as part of regular road reconstruction.

Table 4-3. Residential street summary

Residential area [a]	**Average street width** (ft)	**Street length** (ft)	**Street area** (acres)
A	22	12,833.1	6.5
B	33	3,078.8	2.3
C [b]	30	26,122.6	18.0
D	24	10,783.1	5.9

a. Does not include roadways outside of residential areas presented in Figure 2-12
b. Values do not include Campbell Street

In Residential Area A, residential roads average 22 feet in width, which is the smallest street width in the pilot area. The entire roadway is assumed to be converted into porous pavement.

Residential Area B has the widest street width at 33 feet. A review of the aerial photography does not indicate a need for on-site parking in this area and, therefore, a reduction in impervious surface (9 foot width) is recommended. Final street widths will be 24 feet and will include one parking lane. The average width of roadways in Residential Area C is 30 feet (excluding Campbell Street). A review of the aerial photography does not indicate a need for on-site parking in this area, and therefore a reduction in impervious surface (6 foot width) is recommended. There is no reduction of impervious surfaces proposed for Residential Area A or D.

In addition to reducing imperviousness, two strips of porous pavement, each four feet in width and located along both sides of the curb are proposed to provide treatment of runoff in Residential Areas B, C, and D. The road can be crowned and each porous pavement strip will treat runoff from one-half of the roadway in addition to the driveways, front yards and roofs that drain to the street. In addition, along Campbell Street two eight foot wide strips of porous pavement are modeled adjacent to the curb. The drainage area to this pavement is equal to the roadway (5.4 impervious acres).

The porous pavement design includes a 2 foot-deep gravel bed with a free-flowing underdrain set 1 foot below the pavement. The contributing drainage area would be equal to the pavement itself, driveways, and contributing roof and urban lawn areas treating a maximum of 62.2 impervious acres and 37.4 pervious acres, excluding Campbell Street.

Porous pavement can be used in several other applications within the pilot area. The model assumes that all residential alleys could be converted to porous pavement as green alleys. For green alley applications, the drainage area is assumed to include the alley itself and an additional pervious area equal to two times the area of the alley. Underdrains are assumed in the green alley applications. Porous pavement can also be used effectively in parking lots. Sixty percent of each paved residential parking lot was considered for porous pavement installation, which assumes that driving lanes remain asphalt or concrete while the parking spots are made permeable. All parking lots are assumed to have underdrain systems. The drainage area is represented by the entire parking lot area.

4.3 Rain Barrel

Rain barrels provide for storage and the ability to deliver runoff over time to downstream facilities in residential areas. The standard size of rain barrels in this application is 55 gallons, with a maximum of two units per home. The drainage area to each rain barrel is assumed to be equal to one-quarter of the roof area, ranging from 325 to 617 square feet based on review of impervious cover data. It was assumed that up to 60 percent of homes in the residential area could be retrofitted with up to two rain barrels.

All of the homes with rain barrels are assumed in sequence with bioretention. The sequence assumes that the entire rain barrel volume is released by opening a bottom orifice two days after the end of a storm. The stored water is used to irrigate bioretention vegetation. The rain barrel capacity at any point during the simulation is a function of the amount of water released after a previous event. Back-to-back events are bypassed with no rain barrel benefit if filled to capacity. During cold-weather conditions, the rain barrels are assumed to be disconnected from rooftop downspouts.

4.4 Green Roof

Green roofs can typically be placed on any flat roof surface, assuming the roof can support the additional weight. Potential green roof locations were identified throughout the pilot area using aerial photography and the impervious cover dataset. Because of uncertainty associated with structural suitability of buildings to support green roofs and/or willingness of owners to adopt, fifty percent of the available flat rooftop area (4.9 acres) was assumed to be converted to green roofs.

4.5 Detention Ponds

The potential for regional ponding in the form of large scale bioretention areas were identified throughout the pilot area in vacant and open space areas. Potential BMP areas are identified that treat both residential and other (commercial and institutional) land uses (Figure 2-12). The regional ponding BMP design follows the Bioretention BMP design with the exception of contributing drainage areas. Regional pond drainage areas are assumed to be equal to 18 times the area of the bioretention area, treating approximately one inch of runoff in the contributing watershed. In addition to the regional ponding opportunities identified within the pilot area, there are several large parcels south of Harrison Blvd. and west of the pilot area that could be considered for regional ponding locations, although these areas are not modeled. Regional ponds are modeled as area BMPs in *SUSTAIN*.

5. Determine BMP Configuration and Performance

BMPs are simulated within *SUSTAIN* according to specific design specifications, with the performance modeled using a unit-process parameter-based approach. This contrasts with and has many advantages over most other techniques that simply assign a single percent effectiveness value to each type of practice. *SUSTAIN* predicts BMP performance as a function of its physical configuration, storm size and associated runoff intensity and volume, and moisture conditions within the BMP.

Many of the distributed practices were simulated in aggregate, recognizing the scale and model resolution of the LSPC watershed model. The aggregate approach is a computationally efficient and analytically robust approach that *SUSTAIN* provides for evaluating relative management practice selection and performance at a small subwatershed scale.

An aggregate BMP consists of a series of process-based optional components, including on-site interception, on-site treatment, routing attenuation, and regional storage/treatment. Each aggregate BMP component evaluates storage and infiltration characteristics from multiple practices simultaneously without explicit recognition of their spatial distribution and routing characteristics within the selected watershed. For example, rain barrels within the aggregate BMP network are modeled in series with rain gardens, and service residential rooftop runoff area.

The model is configured so that up to 25 percent of homes in the residential area can have two rain barrels. Likewise, an upper limit of 30 percent of homes can be in sequence with rain gardens. In lieu of modeling discrete rain barrel and bioretention, this approach allows the user to define generalized application rules based on field reconnaissance of BMP opportunity and typical practice. The role of optimization is to determine the relative size (or number) of each BMP component in the generalized aggregate network that achieves the defined management objective at the lowest cost. For this application, the aggregate practice included eight component practices—green roofs, rain barrels, rain gardens, porous pavement, impervious cover conversion, bioswales, regional bioretention, and region stormwater retention ponds. Figure 5-1 is a schematic diagram of aggregate components, drainage areas, and practice-to-practice routing networks.

As shown in Figure 5-1, the rain barrel component collects runoff from rooftops (as part of the impervious surfaces) in residential areas. Runoff from rooftops and green rooftops in commercial and institutional areas is channeled directly to porous pavement. Outflow and bypass from the rain barrel is assumed to flow directly to residential rain gardens, which also capture runoff from open residential areas, typically front yards. Rain garden overflow is then directed to porous pavement, which also captures runoff from impervious transportation surfaces, including roads and alleys. Outflow from porous pavement is captured by curb cuts and catch basins, which route the runoff to bioswales and bioretention facilities. Under field conditions bioswale and bioretention overflows could then flow back to porous pavement if there were downstream areas with surface storage capacity not being fully utilized. The simplification of the aggregate BMP setup does not explicitly represent this feedback loop, however. This is because BMPs can only be designated as either upstream or downstream of one another within an aggregate BMP unit. The aggregate setup does generally represent the treatment provided by the feedback loop, though, by representing the maximum optimized area of all BMPs, where the overall volume treated is the same.

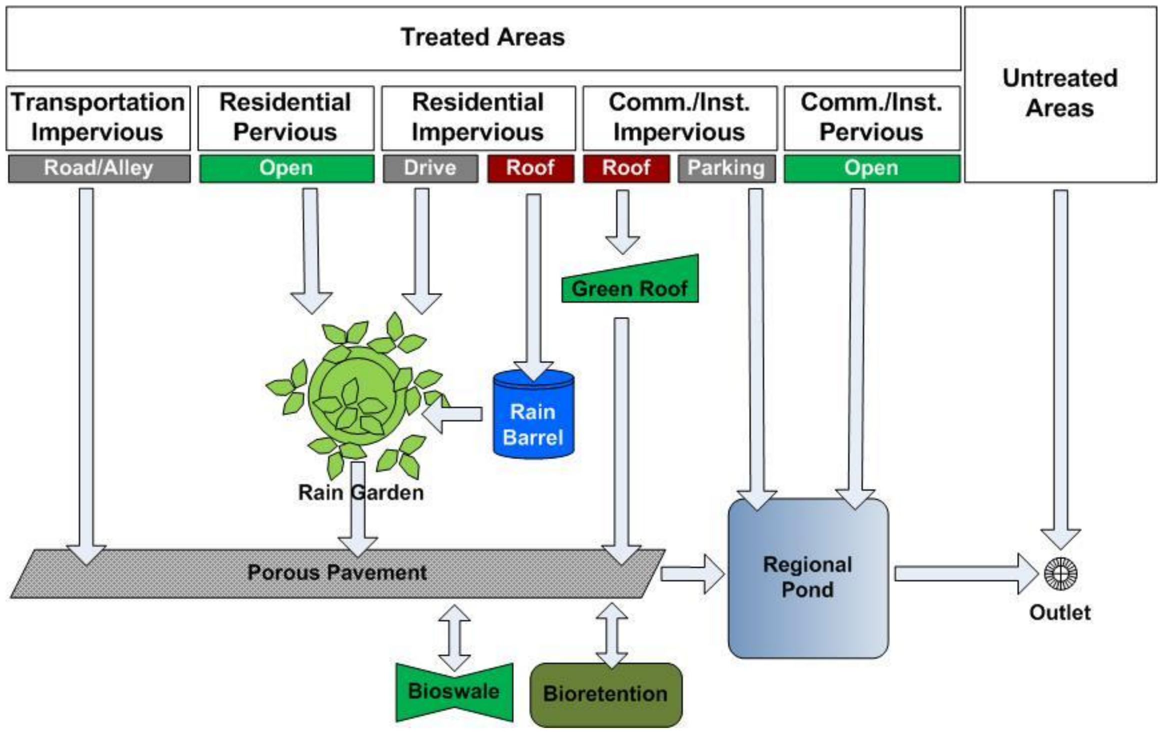


Figure 5-1. Aggregate BMP schematic identifying treatment train options.

Overflows from the porous pavement, bioswale, and bioretention grouping are captured by regional ponds, which also treat runoff from commercial and institutional open areas and parking. Pond overflows are directed to the watershed outlet as is runoff from any untreated areas. Note that the aggregate BMP setup is a tool to determine which BMP(s) are most efficient at achieving an environmental outcome without representing each individual BMP explicitly (e.g. representing a rain barrel for each roof in the study area). The configuration of BMP routing in the aggregate setup are meant to represent a treatment train that makes sense given the BMP design characteristics. Just because a type of BMP is included in the aggregate, does not mean that it will be utilized after optimization analysis is performed, as described below.

To run the optimization analysis, a set of decision variables was identified to explore the best possible combinations of the various BMP practices. For this analysis, the decision variables include:

- Number of fixed-size rain barrel and rain garden units
- Surface area of green roofs, bioretention areas, bioswales, porous pavement, and detention ponds.

Because the decision variable values can range anywhere between zero to a maximum number or size, it is possible for one component within the treatment train to never be selected if it is not cost-effective towards achieving the objective. For example, even though the aggregate BMP setup includes rain barrels, if rain gardens are found to be more cost-effective solution under all conditions, all roof runoff will be directly routed to available rain gardens. In other words, the aggregate BMP provides a menu of options that may or may not be selected depending on cost-effectiveness. During an optimization run, if the size value of zero for a practice is selected, that point will act as a transfer node in the network (i.e.

inflow = outflow with no treatment), and the associated cost that is a function of the number of practices or surface area will in turn compute to be zero.

Table 5-1 summarizes the maximum extent of each practice determined through aerial photography analysis, spatial datasets, and on the basis of best professional judgment. Those values define the upper boundary of the optimization search space. The physical configuration data, infiltration parameters, and cost assumptions for each BMP component are listed in *Table 5-2*.

Infiltration parameters were determined based on the assumed soil substrate. The background infiltration rate refers to the infiltration rate of the native soils below the engineered media. The vegetative parameter, or the percent vegetative cover, and wilting point values presented in the *Low-Impact Development Management Practices Evaluation Computer Module User's Guide* (Tetra Tech, Inc. 2001) were also used to parameterize the model. Wilting point is defined as the minimal soil moisture required to prevent vegetation from wilting.

Table 5-1. Maximum extent of BMPs

BMP	Maximum BMP extent	Total maximum drainage area (acres)	Impervious drainage area (acres)	Pervious drainage area (acres)
Rain Garden (unit)	221	16.4	8.8	7.7
Rain Barrel (unit)	1,058	11.7	11.7	0
Bioswale (acres)	2.0	11.3	9.9	1.4
Bioretention (acres)	0.2	49.4	12.2	37.3
Porous Pavement				
Reduced Impervious Area (acres)	4.2			
Roads and Green Alleys [a] (acres)	12.4	86.5	56.8	29.8
Campbell Street (acres)	2.2	5.4	5.4	0
Parking Lots (acres)	0.9	1.5	1.5	0
Green Roof (acres)	4.9	4.9	4.9	0
Regional Ponding (acres)				
Draining Residential Areas (acres)	8.5	153.0	29.4	123.6
Draining Commercial/Institutional Areas (acres)[b]	7.2	129.4	40.4	89.0

a. Excludes Campbell Street

b. Includes 86 acres of commercial/institutional land and 43.4 acres of residential development

Table 5-2. BMP configuration parameters

Parameter	Rain barrel	Rain garden	Bioswale	Bio-retention	Porous pavement	Green roof	Regional ponding
Physical configuration							
Unit size	55 gallons	150 sf	na	na	na	na	na
Design drainage area (sf or acre)	A – 617 B – 325 C – 509 D – 373	See Table 5-3	na	na	na	na	na
Substrate depth (ft)	na	2	4	4	2	0.3	4
Underdrain storage depth (ft)	na	na	2	2	1	0.1	2
Ponding depth (ft)	na	0.5	0.5	0.5	0.1	0.1	0.5
Infiltration							
Substrate layer porosity	na	0.4	0.4	0.4	0.45	0.5	0.4
Substrate layer field capacity	na	0.25	0.25	0.25	0.055	0.4	0.25
Substrate layer wilting point	na	0.1	0.1	0.1	0.05	0.1	0.1
Underdrain gravel layer porosity	na	na	0.5	0.5	0.5	0.5	0.5
Vegetative parameter, A	na	1	1	1	1	0.6	1
Background infiltration rate (in/hr)	na	0.10	0.10	0.10	0.10	na	0.10
Media final constant infiltration rate (in/hr)	na	0.5	0.5	0.5	1	1	0.5

Table 5-3. Drainage area to each rain garden

Area draining to each rain garden	Residential Area			
	A	B	C	D
Total pervious area treated (SF)	2,584	0	1,553.5	1,434
Total impervious area treated (SF)	2,299	0	1,396.5	1,026

6. BMP Costs

Cost functions are mathematical formulations used to estimate financial expenditures associated with BMP implementation. These represent the combined costs of specific BMP designs, materials, land / space requirements, and operation / maintenance. Cost estimates are essential for the optimization phase of the project.

The purpose of this activity is to ensure that occurs to develop appropriate cost functions. Comprehensive work on stormwater BMP costs was conducted as part of the Rogue River National Wet Weather Demonstration Project in Michigan (*Cost Estimating Guidelines: Best Management Practices and Engineering Controls*, 1997 and 2001 update). Some cost estimates for stormwater BMPs are available as part of local watershed plans, such as the *St. Joseph River Watershed Management Plan* (Indiana and Michigan).

Other work conducted in the Great Lakes Region includes a University of Minnesota report *The Cost and Effectiveness of Stormwater Management Practices*. University of Minnesota staff collected and analyzed construction, operation, and maintenance cost data for a range of stormwater management practices. These included dry detention basins, wet basins, sand filters, constructed wetlands, bioretention filters, infiltration trenches, and swales using literature reported on existing sites across the United States.

Cost information has also been compiled in other parts of the country to support BMP targeting and optimization efforts. Examples include work in the Charles River, Massachusetts, Vermont, and Southern California.

Cost data represents life cycle costs by considering three categories of BMP costs:

- Probable Construction Costs – The initial cost to construct the BMP
- Annual Operation and Maintenance – The annual costs to maintain the BMP
- Repair and Replacement Costs – The additional costs to repair or replace the BMP

A standard unit cost was defined for each BMP category, since the range of BMPs was unknown and expected to vary significantly. Each unit cost was converted to 2012 dollars by applying a three percent inflation rate from the published year of the cost data to 2012. A discount rate of 3 percent was used for converting annual operation and maintenance and repair and renewal costs to present value.

The lifecycle period was defined as 20-years to take into account costs for replacing some BMPs. Several of the sources used to derive costs data defined engineering and design and contingency factors based upon a percent of the base construction cost, while other sources intentionally omitted them. A default 15 percent engineering and design cost factor and 25 percent contingency cost factor were assigned to probable construction costs when no values were provided. No land, administration, demolition, or legal cost factors were defined for any of the probable construction costs.

The following sources were reviewed when defining the lifecycle costs:

- WERF. 2009. BMP and LID Whole Life Cost Models version 2.0. Water Environment Research Foundation.
- Center for Neighborhood Technology. June 30, 2009. National Green Values Calculator.
- University of Minnesota. Peter T. Weiss, John S. Gulliver, Andrew J. Erickson. June 2005. The Cost and Effectiveness of Stormwater Management Practices. Prepared for Minnesota Department of Transportation.

- Low Impact Development Center, Inc. November, 2005. Low Impact Development for Big Box Retailers. Prepared for U.S. Environmental Protection Agency. Prepared by the Low Impact Development Center, Inc.

The City of Toledo, Ohio and Burnsville, Minnesota provided cost data for design and construction of bioswales and bioretention, respectively. Additional Tetra Tech projects and best professional judgment were also considered when defining the range of lifecycle unit costs.

Table 6-1. BMP costs

Parameter	Rain barrel	Rain garden	Bioswale	Bio-retention	Porous pavement	Green roof	Regional ponding
Life Cycle Cost Data							
Lifecycle Unit Cost [A+B+C] (NPV)	$165.69 ea	$13.6/ft^2	$36.80/ft^2	$38.73/ft^2	$16.58/ft^2	$44.54/ft^2	$38.73/ft^2
A) Probable Unit Cost	$95.00 ea.	$7.80/ft^2	$26.07/ft^2	$28.00/ft^2	$12.38/ft^2	$27.17/ft^2	$28.00/ft^2
Annual O&M	$0	$0	$0.72/ft^2	$0.72/ft^2	$0.28/ft^2	$1.09/ft^2	$0.72/ft^2
B) Annual O&M (NPV)	$0	$0	$10.73/ft^2	$10.73/ft^2	$4.20	$16.26/ft^2	$10.73/ft^2
C) Repair & Replacement (NPV)	$70.69 ea.	$5.8/ft^2	0	0	0	$1.11/ft^2	0
BMP Lifecycle Period	10-yrs	10-yrs	20-yrs	20-yrs	20-yrs	20-yrs	20-yrs

7. BMP Optimization Analysis

7.1 Formulation and Volume Reduction Targets

The optimization objectives were to:

1) maximize annual volume reduction, while
2) minimizing total implementation cost (lifecycle costs including design, construction, and operation and maintenance).

The NSGA-II optimization approach was the computation approach that was used for this analysis. NSGA-II is a multi-objective, evolutionary algorithm that uses the elitist approach where solutions are sorted on the basis of the degree of dominance within the population (i.e., if a given solution is not dominated by any other solution, that solution has the highest possible fitness). In addition, the algorithm seeks to preserve diversity along the first non-dominated front so that the entire Pareto-optimal region is found (USEPA 2009). As a result, the optimization outcome defines a set of solutions that show the maximum achievable volume reduction at each minimum-cost interval.

Hydrologic targets were selected for the Beauty Creek watershed on the basis of the average annual volume reduction cost-effectiveness curve generated for the pilot area (Figure 7-1). Cost-effectiveness curve solutions are determined by the aggregate BMP decision variables where the average annual volume control results from the combination and size of BMPs simulated, which in turn have an associated cost. In these figures, the small points represent *all solutions* that were evaluated during optimization; the larger orange points along the left-and-upper-most perimeter of the curve represent the lowest cost options at each volume reduction target interval.

To support the evaluation of a range of possible BMP implantation strategies, hydrologic targets, or cost-effectiveness curve solutions, were selected at the lowest (23 percent) and highest (~65 percent) volume reductions simulated for the available BMP opportunities, as well as at intervals of 10 percent between thirty and sixty percent reduction. These six solutions are presented in Figure 7-1 as the largest yellow points, pinpointed with intersecting lines. Table 7-1 summarizes implementation costs for the set of selected volume reduction solutions.

Table 7-1. Flow volume target solutions from Beauty Creek pilot area

Solution	Flow volume reduction (%)	Flow volume reduction (ac-ft)	Cost ($)
96	23%	159.7	4,724,020
102	30%	205.6	6,546,568
55	40%	280.6	9,709,669
170	50%	345.2	13,447,445
56	60%	415.8	21,228,722
49	65%	451.9	29,567,262

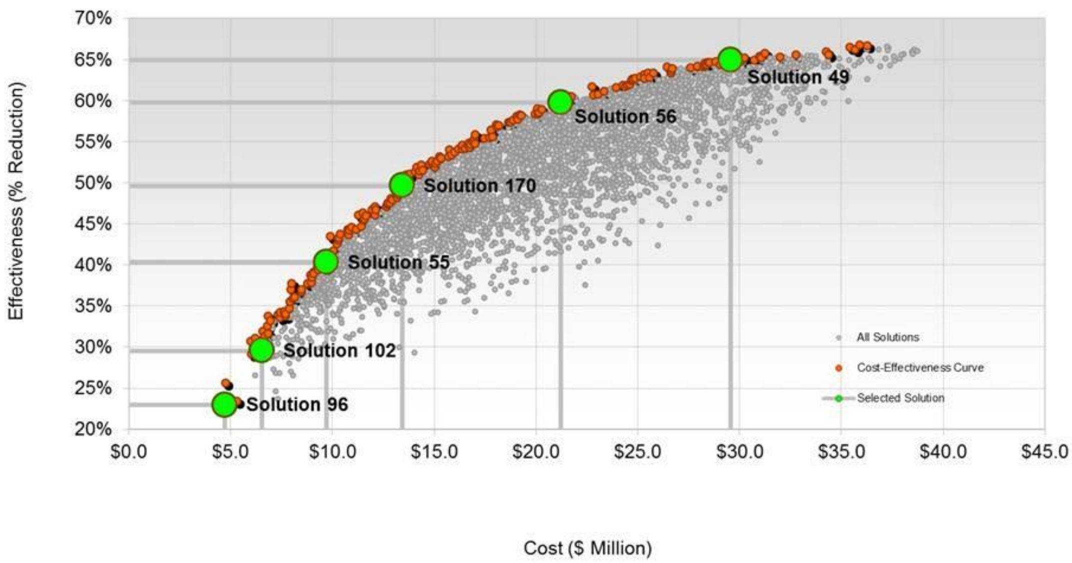


Figure 7-1. Maximum volume control cost-effectiveness curve for Beauty Creek pilot area.

As can be seen in Table 7-1, as the level of treatment increases the marginal return on cost, or the treatment gained by spending and additional dollar, decreases. This is also illustrated in Figure 7-2. Interestingly for the various solutions the marginal return is relatively constant between 23 percent and 30 percent volume reduction. After this point the marginal cost of additional volume reduction begins to increase sharply, depicted as a decreasing slope in the marginal return curve. Ideally, when deciding an appropriate level of implementation it should be first determined what level of marginal return on capital investment is acceptable.

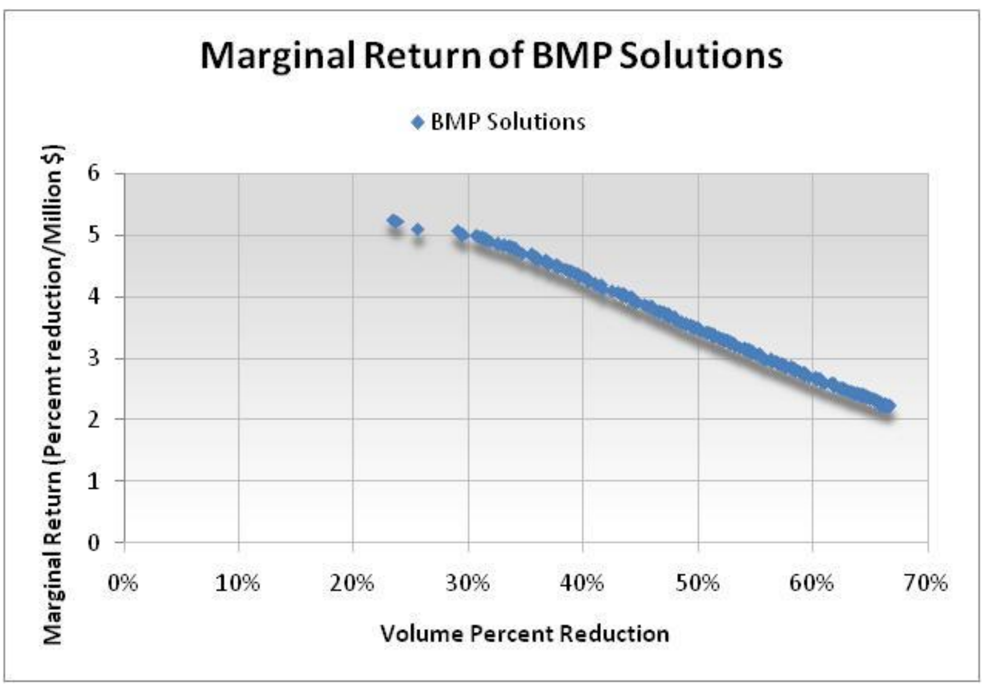


Figure 7-2. Marginal return of BMP solutions as volume reduction increases.

7.2 BMP Screening Analysis

To support the evaluation of the cost-effectiveness curve generated for the Beauty Creek pilot area BMP opportunities, a BMP screening analysis was performed to assess the potential relative contribution to volume reduction of each BMP. Figure 7-3 illustrates the volume reduction of each BMP in isolation as utilization increases. For regional ponds and porous pavement volume reduction is also significantly affected by BMP spatial orientation or location within the pilot area. As a result at each level of utilization various levels of volume control are possible. For the other BMP types spatial orientation is less significant and volume reduction is almost completely determined by utilization alone.

As shown in Figure 7-3 and Table 7-2, porous pavement provides the greatest potential volume reduction followed closely by regional ponds. The potential volume reduction of the other BMPs drops below ten percent thereafter with bioswales, rain gardens, impervious conversion, bioretention, green roofs, and rain barrels providing decreasing levels of volume control in that order. Table 7-2 presents the maximum volume control identified by the screening analysis and by the maximum build-out of BMP opportunities. The reason the volume reductions differ between the two is that the screening analysis looked at each BMP in isolation, while the maximum build-out scenario represents BMPs in a network. Therefore, some volume reduction opportunity is lost for BMPs in the maximum build-out scenario depending on its position in the treatment train and its maximum treatment possibility.

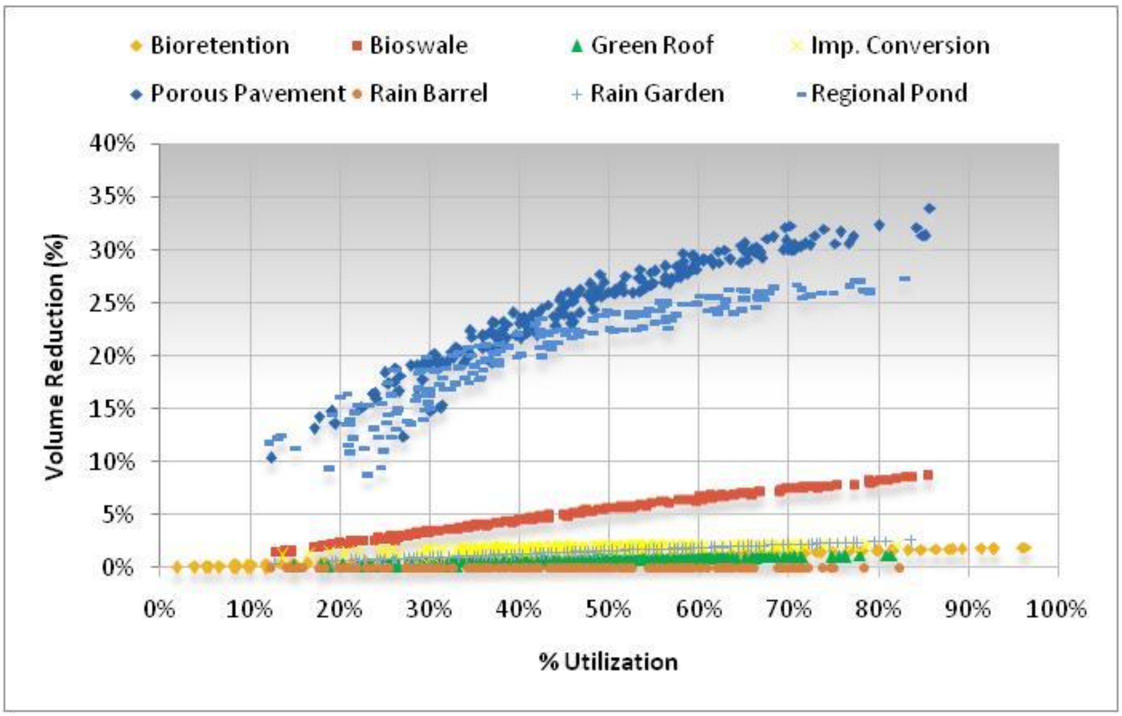


Figure 7-3. Screening analysis of BMP volume reduction as a function of percent utilization.

Table 7-2. Maximum BMP volume reduction for the screening analysis

BMP	Volume Reduction (%)	
	Screening Analysis	Max Build-out
Porous Pavement	34%	31%
Regional Pond	27%	28%
Bioswale	8.8%	3.0%
Rain Garden	2.6%	2.7%
Impervious Conversion	2.1%	2.1%
Bioretention	1.8%	2.7%
Green Roof	1.1%	1.4%
Rain Barrel	0.00008%	0.00005%
Total	78%	71%

8. *SUSTAIN* Target / Solution Model Results

The BMP configurations for the six selected solutions were configured as independent model runs for the Beauty Creek pilot area to investigate the level of implementation of each and further analyze BMP functionality and effectiveness. Model results include BMP utilization, percentage reduction of average annual flow and associated processes, and BMP efficiency measured as captured rainfall. The model results are presented in two sections. The first assesses the model results for the Beauty Creek pilot area as a whole. The second looks at the results for each of the seven subwatersheds within the Pilot area (Figure 8-1) to determine the relative contribution of each.

8.1 Pilot Area Wide Results

The following section presents model results for the pilot area as a whole. The model results for the entire area inform the overall trends of BMP implementation for each BMP configuration solution.

8.1.1 BMP Utilization

The percent utilization of each BMP for the six target solutions is shown in Figure 8-2. Percent utilization for each solution is the area or number of BMPs in the selected solution divided by the maximum potential area or number of BMPs in the model. Figure 8-2 illustrates how utilization changes for each BMP as cost and percent volume control increases. The extent to which each practice is used for the six selected solutions is also presented in Table 8-1, including the maximum area for each practice as defined by the BMP opportunity assessment and the solution area represented in the *SUSTAIN* model simulations.

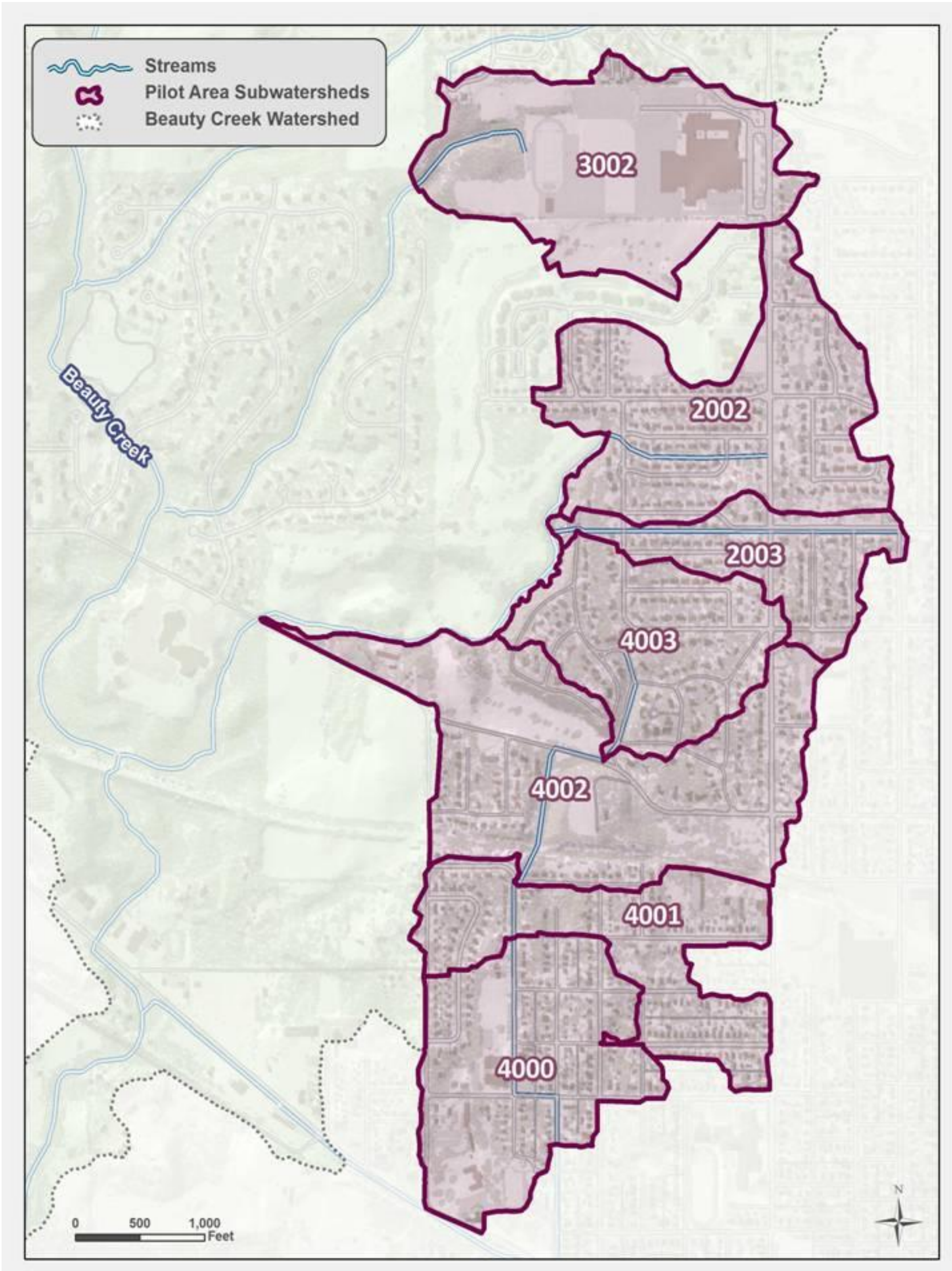


Figure 8-1. Beauty Creek pilot area subwatershed network.

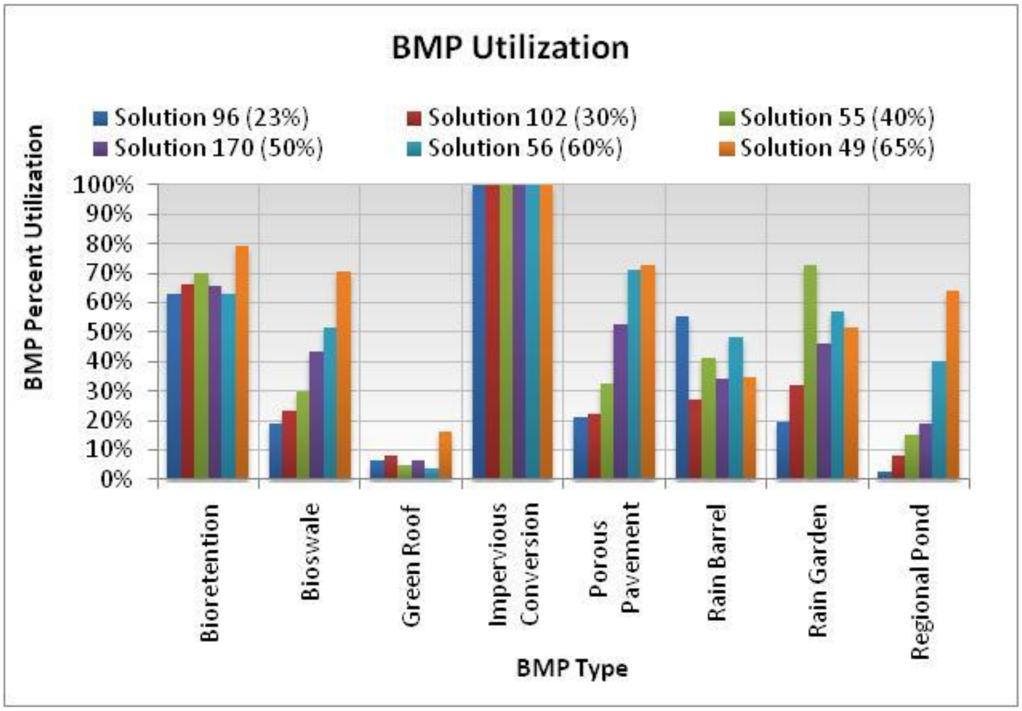


Figure 8-2. Best management practice percent utilization in the Beauty Creek pilot area.

Table 8-1. BMP total opportunity and amount utilized

BMP	Extent Unit	Maximum Extent	Solution BMP Extent					
			Solution 96 (23%)	Solution 102 (30%)	Solution 55 (40%)	Solution 170 (50%)	Solution 56 (60%)	Solution 49 (65%)
Bioretention	Acres	0.20	0.13	0.13	0.14	0.13	0.13	0.16
Bioswale	Acres	2.09	0.40	0.48	0.62	0.90	1.08	1.48
Green Roof	Acres	4.86	0.32	0.39	0.25	0.31	0.20	0.79
Porous Pavement	Acres	15.50	3.31	3.45	5.04	8.12	11.03	11.24
Rain Barrel	Units	1,059	588	286	436	364	510	367
Rain Garden	Units	221	44	70	160	102	125	113
Regional Pond	Acres	15.71	0.41	1.24	2.35	2.99	6.28	10.07
Impervious Conversion	Acres	4.17	4.17	4.17	4.17	4.17	4.17	4.17

In general, as the level of treatment increases from 23 percent to 65 percent the utilization of each BMP either steadily increases or remains relatively constant. Best management practices for which the increasing trend is observed include bioswales, porous pavement, rain gardens and regional ponds, while the utilization of bioretention, green roofs, and rain barrels remains relatively constant throughout all scenarios. The reasons for these trends can be attributed to two factors: 1) the maximum extent of each BMP and 2) unit cost. Impervious conversion utilization is 100 percent for all scenarios because implementation costs are assumed to be zero (see Section 4.2).

Best management practices that show consistent increasing utilization as the level of volume control increases either have relatively large opportunity areas for implementation (bioswale, porous pavement, and regional ponds) or low unit cost (rain garden). These characteristics lend themselves to increased implementation to achieve larger volume control. The other BMPs either have small opportunity areas (bioretention and rain barrels) or have large unit costs (green roofs). For the BMPs with small maximum extents a consistently high level of utilization is seen. This can be attributed to most of the volume control being realized in the lowest volume reduction solution, resulting in further implementation having minimal effect. Green roofs have the highest unit cost ($44.54 per square feet); therefore it is less likely to be selected during optimization.

Best management practice utilization can also be pictured as the BMP component cost of the cost-effectiveness as shown in Figure 8-3. The trends in utilization described for the six solutions can be seen is this curve where regional pond, porous pavement, bioswale, and rain garden costs steadily increase with increasing volume control, while the costs of other BMPs is relatively constant. Note that the utilization of green roofs does begin to show increases for the largest volume reduction control scenarios (greater than 60 percent), where increased volume control necessitates its implementation. This trend can also be seen in Figure 8-2.

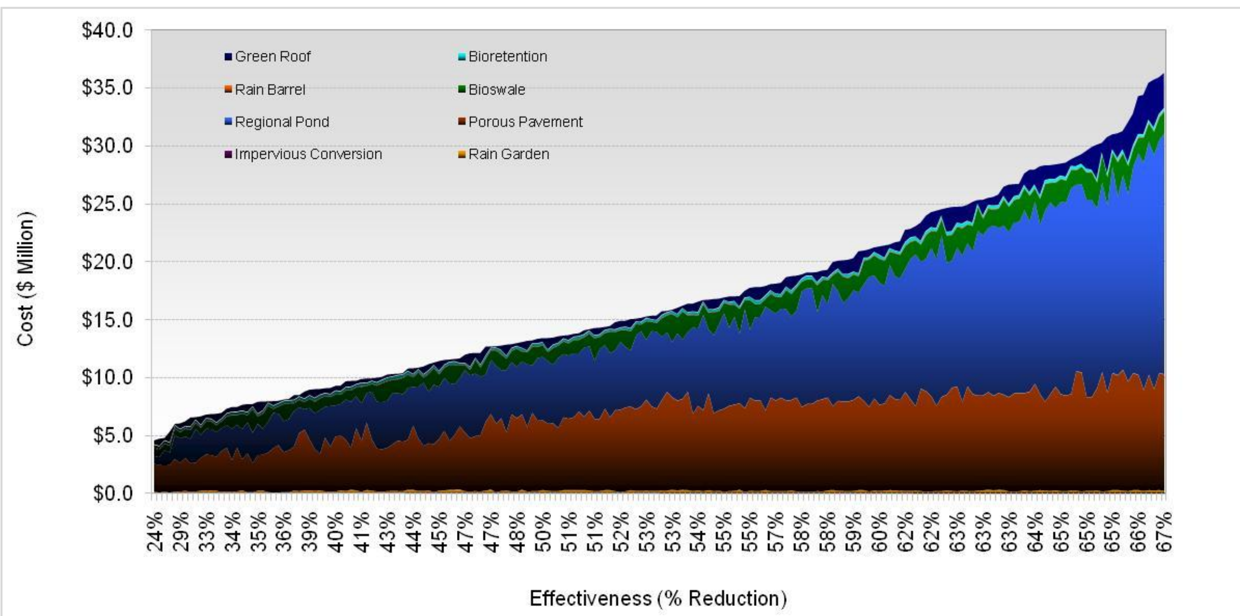


Figure 8-3. BMP component costs of the cost-effectiveness curve for the Beauty Creek pilot area.

8.1.2 Volume Reduction

One of the goals of BMP implementation is the reduction of storm flow volumes to protect downstream resources. Figure 8-4 shows the total volume reduction provided by each BMP for the selected flow reduction solutions in the Beauty Creek pilot area. The flow volume reduction provided by each BMP is achieved through a combination of groundwater recharge and evapotranspiration. Total volume reduction and the percent attributed to groundwater recharge and evapotranspiration provided by the BMPs for each scenario is given in Table 8-2. The volume reductions have been color coded for each solution to show the relative contribution of each BMP where blue indicates lowest volume treated, yellow is intermediate, and red highlights the highest volume reductions.

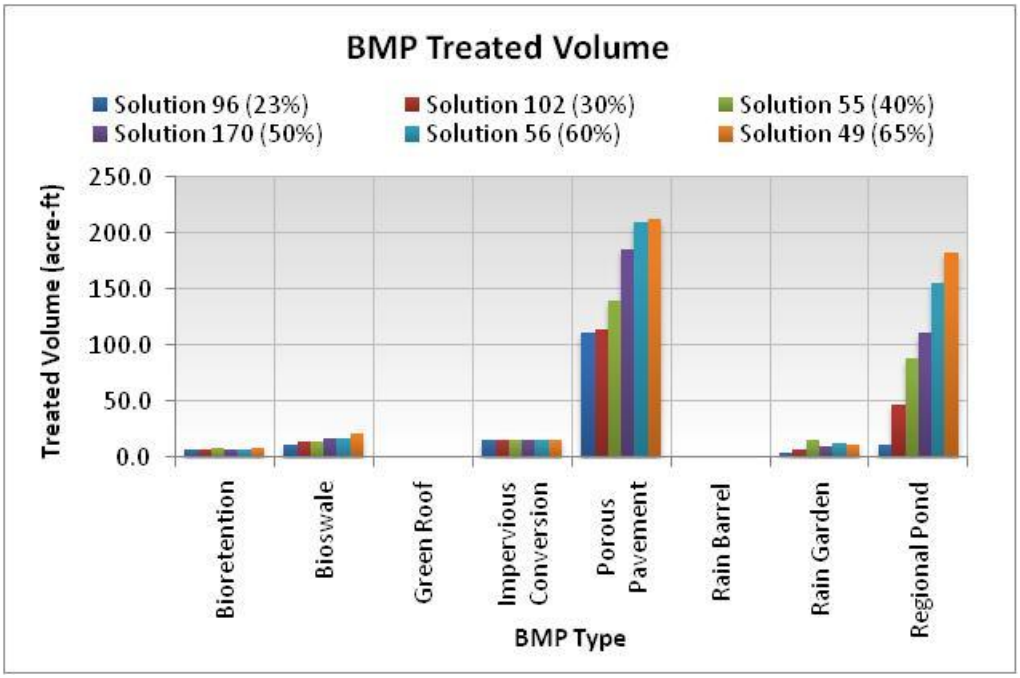


Figure 8-4. Best management practice volume for the Beauty Creek pilot area.

Table 8-2. BMP volume reduction summary.

BMP	Solution 96 (23%)			Solution 55 (40%)			Solution 170 (50%)			Solution 56 (60%)			Solution 49 (65%)		
	Vol. (af)	% ET	% GW	Vol. (af)	% ET	% GW	Vol. (af)	% ET	% GW	Vol. (af)	% ET	% GW	Vol. (af)	% ET	% GW
Bio-retention	7.21	5	95	7.72	5	95	7.21	5	95	7.06	5	95	8.43	5	95
Bioswale	11.41	9	90	13.96	12	88	16.86	14	85	17.09	17	82	20.83	18	80
Green Roof	0.61	98	0	0.47	98	0	0.59	98	0	0.38	98	0	1.56	98	0
Porous Pavement	111.06	5	95	140.07	6	94	184.80	7	93	209.23	8	92	212.08	8	92
Rain Barrel	0.0004	0	0	0.0003	0	0	0.0002	0	0	0.0003	0	0	0.0002	0	0
Rain Garden	4.17	10	90	15.64	10	90	10.24	9	91	12.43	9	90	11.29	9	90
Regional Pond	10.41	11	89	87.81	7	92	110.63	7	92	154.72	11	88	182.86	15	84
Impervious Conversion	14.86	63	37	14.86	63	37	14.86	63	37	14.86	63	37	14.86	63	37

Blue – red denotes low – high
Vol.: Volume in acre-feet
%ET: Percent evapotranspiration
%GW: Percent groundwater recharge

As show in Figure 8-4 and Table 8-2 the relative volume reduction of each BMP is largely consistent across all solutions. Porous pavement shows the largest volume reductions for all scenarios, while regional ponds, generally, show the second largest reductions, which increase as total volume reduction increases, ultimately almost equaling what is achieved for porous pavement for the 65 percent reduction scenario (Solution 49). Bioretention, bioswale, and rain garden BMPs show comparable volume reduction across all scenarios. Green roofs show small, but generally increasing volume reductions, while rain barrels provide the smallest volume reductions consistently across all solutions.

The volume reduction attributed to groundwater recharge and evapotranspiration for each BMP is consistent across solutions and is a function of the BMP designs, which are outlined in Table 8-2. Green roofs are only capable of volume reduction through evapotranspiration, while bioretention, bioswales, porous pavement, rain garden and regional ponds act primarily to infiltrate runoff. Impervious areas converted to pervious land show a relatively even split between evapotranspiration and infiltration, primarily as a result of the slow infiltration rates of the native soils (see Section 2.2.2).

As another layer of analysis, the volume reduction of each scenario was broken out as a percentage attributable to each BMP as shown in Figure 8-5. Percentage closely mirror overall volumes, where regional ponds and porous pavement provide the majority of treatment, followed by impervious conversion, bioswales, rain gardens, and bioretention, which are all comparable, and finally green roofs and rain barrels.

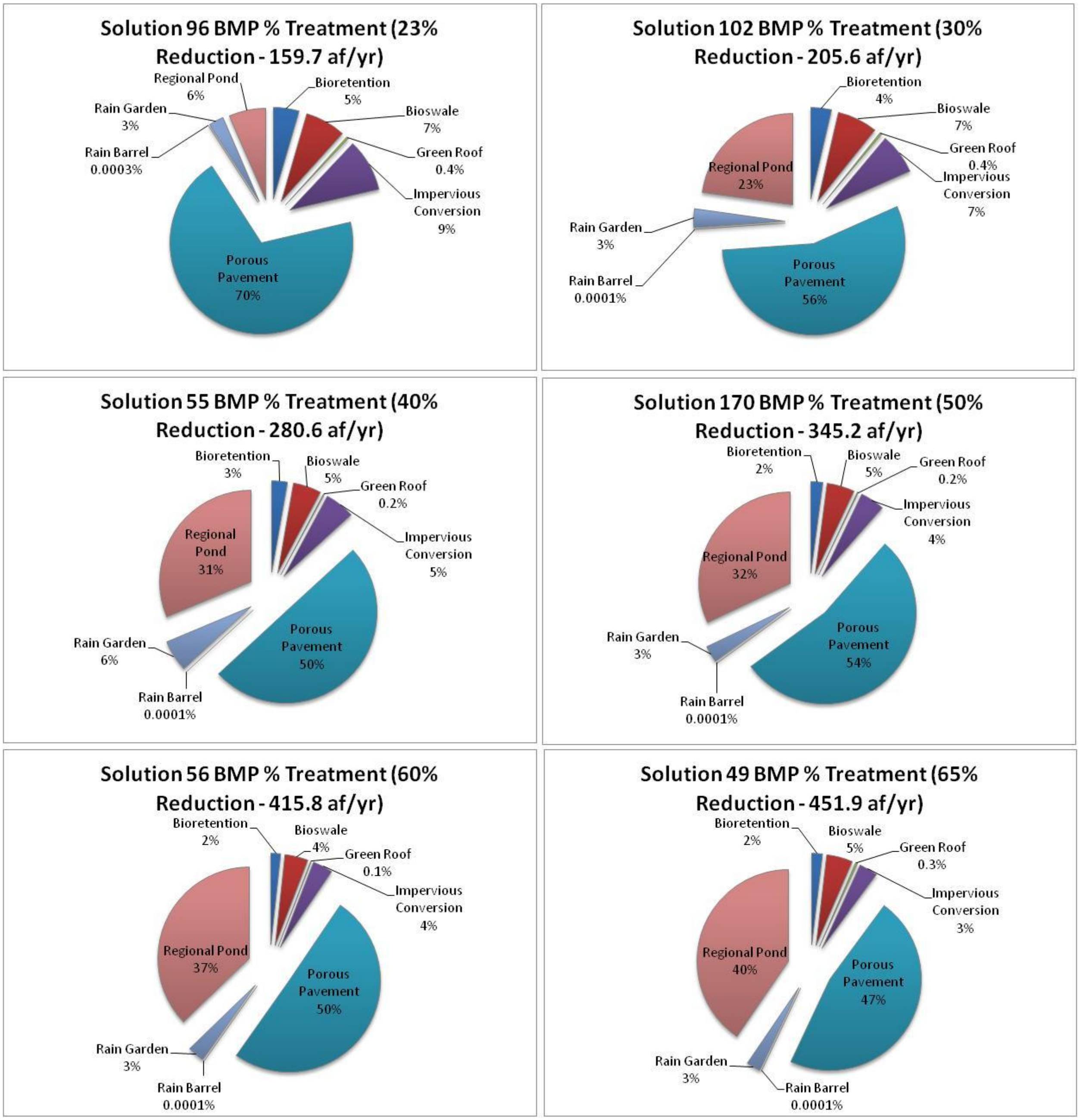


Figure 8-5. Solution volume reduction and BMP contributions.

8.1.3 Treatment Depths

To investigate the efficiency of each BMP, the treatment depth of each was assessed for all solutions. Treatment depth was calculated as the treated volume divided by the contributing drainage area. If a BMP was 100 percent efficient it would, in effect, treat all rainfall that was captured by its drainage area. The average annual rainfall for the modeled time period (1992–1994) was 41.8 inches. The closer the treatment depth to this value the more efficient the BMP is at treating captured rainfall. Figure 8-6 and Table 8-3 present treated volume and depth of each BMP for the six selected solutions. In Table 8-3 the treatment depths have been color coded for each solution to show the relative efficiency of each BMP where blue is indicates lowest depth treated, yellow is intermediate, and red highlights the highest depth treated.

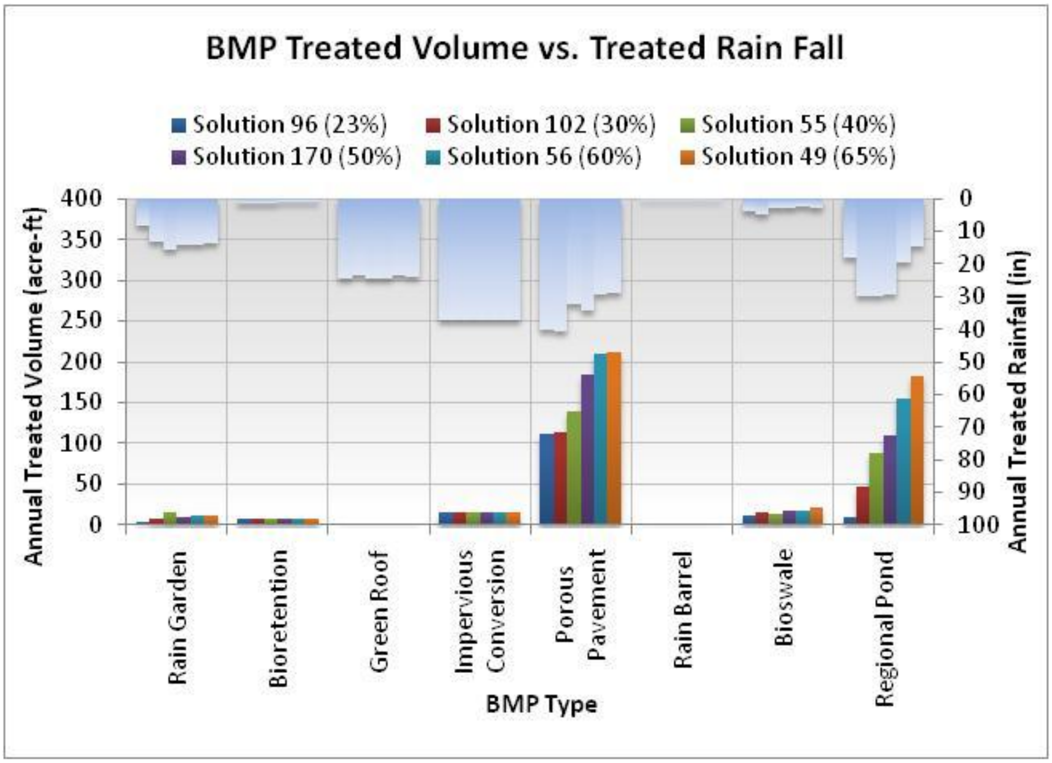


Figure 8-6. BMP volume reduction and treatment depths.

On the basis of treatment depths the most consistently efficient BMP is impervious conversion. Its efficiency does not change across solutions as a result of the same configuration being used for each. Porous pavement achieves efficiencies greater than impervious conversion, but that efficiency begins to drop when volume reductions exceed 30 percent (Solutions 102). In fact, the treatment efficiencies of all BMPs generally decrease when the 30 percent threshold is passed, most markedly for porous pavement and regional ponds. This indicates that as the drainage areas of the BMPs expand they are less able to treat the volumes generated by the largest storms. Interestingly green roofs have fairly high treatment depths indicating high efficiency, followed by rain gardens, bioswales, bioretention, and finally rain barrels. That rain barrels have such a low treatment depth indicates that they are generally not able to capture the majority of runoff directed to them, leading to frequent overflows.

Table 8-3. BMP volume reduction and treatment depths

BMP	Solution 96 (23%)		Solution 55 (40%)		Solution 170 (50%)		Solution 56 (60%)		Solution 49 (65%)	
	Depth (in)	Vol. (af)	Depth (in)	Vol. (af)	Depth (in)	Vol. (af)	Depth (in)	Vol. (af)	Depth (in)	Vol. (af)
Rain Garden	8.3	4.2	15.4	15.6	14.2	10.2	14.1	12.4	13.6	11.3
Bioretention	1.5	7.2	1.2	7.7	1.0	7.2	0.8	7.1	0.9	8.4
Green Roof	24.5	0.6	24.6	0.5	24.6	0.6	23.6	0.4	24.1	1.6
Porous Pavement	40.1	111.1	32.1	140.1	34.2	184.8	29.3	209.2	29.0	212.1
Rain Barrel	0.0014	0.0004	0.0014	0.0003	0.0013	0.0002	0.0014	0.0003	0.0010	0.0002
Bioswale	4.0	11.4	3.1	14.0	3.0	16.9	2.3	17.1	2.8	20.8
Regional Pond	18.1	10.4	29.7	87.8	29.2	110.6	19.7	154.7	14.5	182.9
Impervious Conversion	37.3	14.9	37.3	14.9	37.3	14.9	37.3	14.9	37.3	14.9

Blue – red denotes low – high
Vol.: Volume in acre-feet

8.1.4 Summary of Results for Pilot Area-Wide Analysis

Below is a summary of observations from the pilot area-wide analysis:

- The level of BMP utilization generally increases or remains constant as total treatment volumes increase. Whether utilization increases, as for bioswales, porous pavement, rain gardens, and regional ponds, or is stable, as for bioretention, green roofs, and rain barrels, seems to be dependent on two factors: 1) maximum BMP opportunity and 2) unit cost. BMPs that show consistent increasing utilization as the level of volume control increases either have relatively large opportunity areas for implementation (bioswale, porous pavement, and regional ponds) or low unit cost (rain garden). BMPs that show stable utilization either have small opportunity areas (bioretention and rain barrels) or have large unit costs (green roofs).
- The relative volume reduction of each BMP is largely consistent across all solutions. Porous pavement shows the largest volume reductions for all scenarios, while regional ponds, generally, show the second largest reductions, which increase as total volume reduction increases. Bioretention, bioswale, and rain garden BMPs show comparable volume reduction across all scenarios. Green roofs show small, but generally increasing volume reductions, while rain barrels provide the smallest volume reductions consistently across all solutions.
- The volume reduction attributed to groundwater recharge and evapotranspiration for each BMP is consistent across solutions and is a function of the BMP designs (Table 5-2).
- On the basis of treatment depths the most consistently efficient BMP is impervious conversion. Porous pavement achieves efficiencies greater than impervious conversion, but that efficiency begins to drop when volume reductions exceed 30 percent (Solution 102). The treatment efficiencies of all BMPs generally decrease when the 30 percent threshold is passed. This indicates that as the drainage areas of the BMPs expand they are less able to treat the volumes generated by the largest storms. The low treatment depth for rain barrels indicates that they are generally not able to capture the majority of runoff directed to them, leading to frequent overflows.

8.2 Subwatershed Results

The following section presents model results for each of the seven subwatersheds within the Beauty Creek pilot area (Figure 8-1). The model results for each subwatershed are, in large part, determined by the BMP opportunities identified in each as described in Section 4 and taken together explain the overall trends described in the pilot area wide analysis.

8.2.1 BMP Utilization

Generalized utilization across all areal BMPs for each watershed was also assessed. Rain barrel utilization was not included in this aggregate analysis because of its consistently low treatment volumes. BMP utilization by subwatershed is shown in Figure 8-7 and Table 8-4. In general, subwatersheds 2002, 2003, 4000, and 4001 showed the greatest BMP utilization across all solutions. Subwatersheds 4002 and 4003 showed similar level of utilization for most solutions, while subwatershed 3002 consistently showed the lowest utilization across all solutions.

Similar to what was observed throughout the pilot area as a whole, in general, as the level of treatment increases the utilization of all BMPs generally increases, particularly for the greatest volume reduction solutions. The trend is a lot less well defined however, and utilization shows a lot more variability across solutions. This is because though utilization can be attributed to the two factors, the maximum extent of each BMP and unit cost, BMP opportunity within each subwatershed is constrained differently largely in accordance with land use distribution. Therefore utilization as a function of optimization is more likely to shuffle BMP combinations in an effort to find the most cost-effective solution. In general however, the utilization of a BMP within a subwatershed is more likely to show an increasing trend the larger the BMP opportunity, which is generally the case for porous pavement and regional ponds.

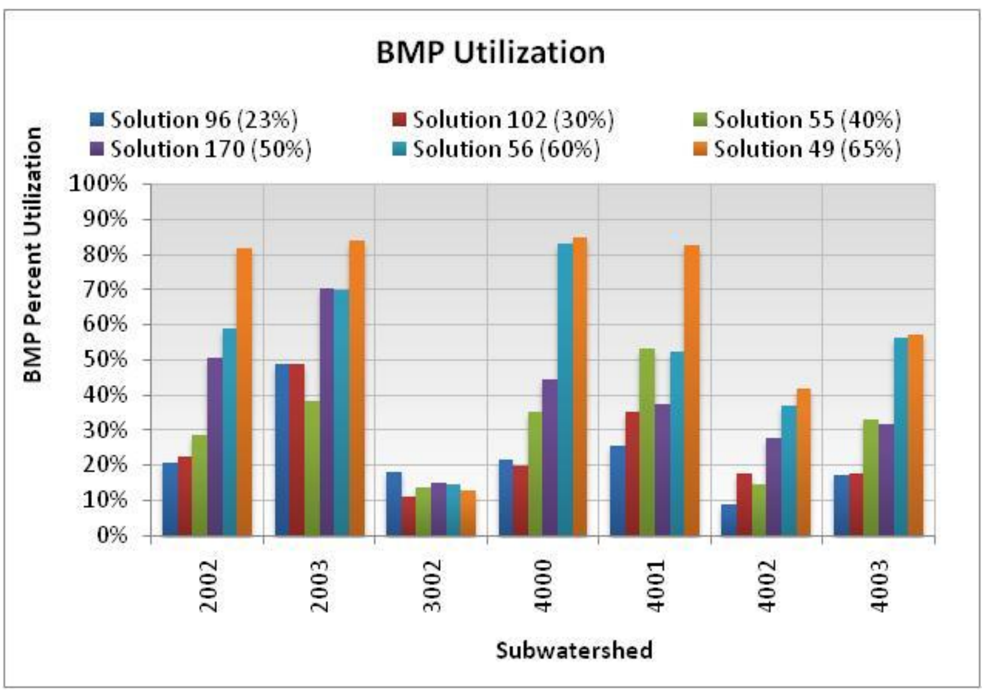


Figure 8-7. BMP percent utilization *(*does not include rain barrels in analysis*)*.

Table 8-4. BMP percent utilization by subwatershed

Sub-watershed	Maximum Extent (acres)	Solution BMP Utilization					
		Solution 96 (23%)	Solution 102 (30%)	Solution 55 (40%)	Solution 170 (50%)	Solution 56 (60%)	Solution 49 (65%)
2002	9.1	20.6%	22.4%	28.6%	50.7%	58.9%	81.8%
2003	3.4	48.8%	48.7%	38.5%	70.3%	69.9%	83.9%
3002	3.6	18.2%	10.8%	13.7%	15.1%	14.3%	12.6%
4000	6.5	21.4%	19.9%	35.2%	44.3%	83.1%	84.7%
4001	6.2	25.6%	35.1%	53.1%	37.4%	52.2%	82.8%
4002	9.0	8.8%	17.8%	14.6%	27.6%	36.7%	41.7%
4003	5.5	17.0%	17.8%	33.1%	31.8%	56.3%	57.1%

Blue – red denotes low – high

8.2.2 *Volume Reduction*

Figure 8-8 and Figure 8-9 show the total volume reduction provided by each BMP for the selected flow reduction solutions in the Beauty Creek pilot area subwatersheds. The flow volume reduction provided by each BMP is achieved through a combination of groundwater recharge and evapotranspiration. Porous pavement and regional ponds generally show the largest volume reductions for all scenarios in all subwatersheds, with the exception of subwatersheds 2003 and 4003 where the opportunities for regional ponds are very small. Bioretention, bioswale, and rain garden BMPs show comparable volume reduction across all scenarios. Green roofs generally show the second smallest volume reductions, followed by rain barrels, which provide the smallest volume reductions consistently across all subwatersheds and solutions. Note that only subwatersheds 4002 and 4003 have bioretention area opportunities, which accounts for the zero volume reduction totals for this BMP in the other subwatersheds (2002, 2003, 3002, 4000, and 4001).

Interestingly, no one subwatershed always shows the greatest volume reduction (Figure 8-10 and Table 8-5). Subwatershed 2002 shows the greatest volume reductions for the 50, 60, and 65 percent flow reduction scenarios. This subwatershed showed high levels of utilization for these scenarios and also has the largest area of BMP opportunities (9.1 acres). Subwatersheds 4000, 4002, and 4001 showed the greatest volume reductions for the 23, 30, and 40 percent flow reduction scenarios, respectively. Subwatershed 4002 has the second largest area of BMP opportunities (9.0 acres), but has consistently low percent utilization. Subwatersheds 4000 and 4001 have very similar areas of BMP opportunity, 6.5 and 6.2 acres, respectively, and both show high levels of utilization.

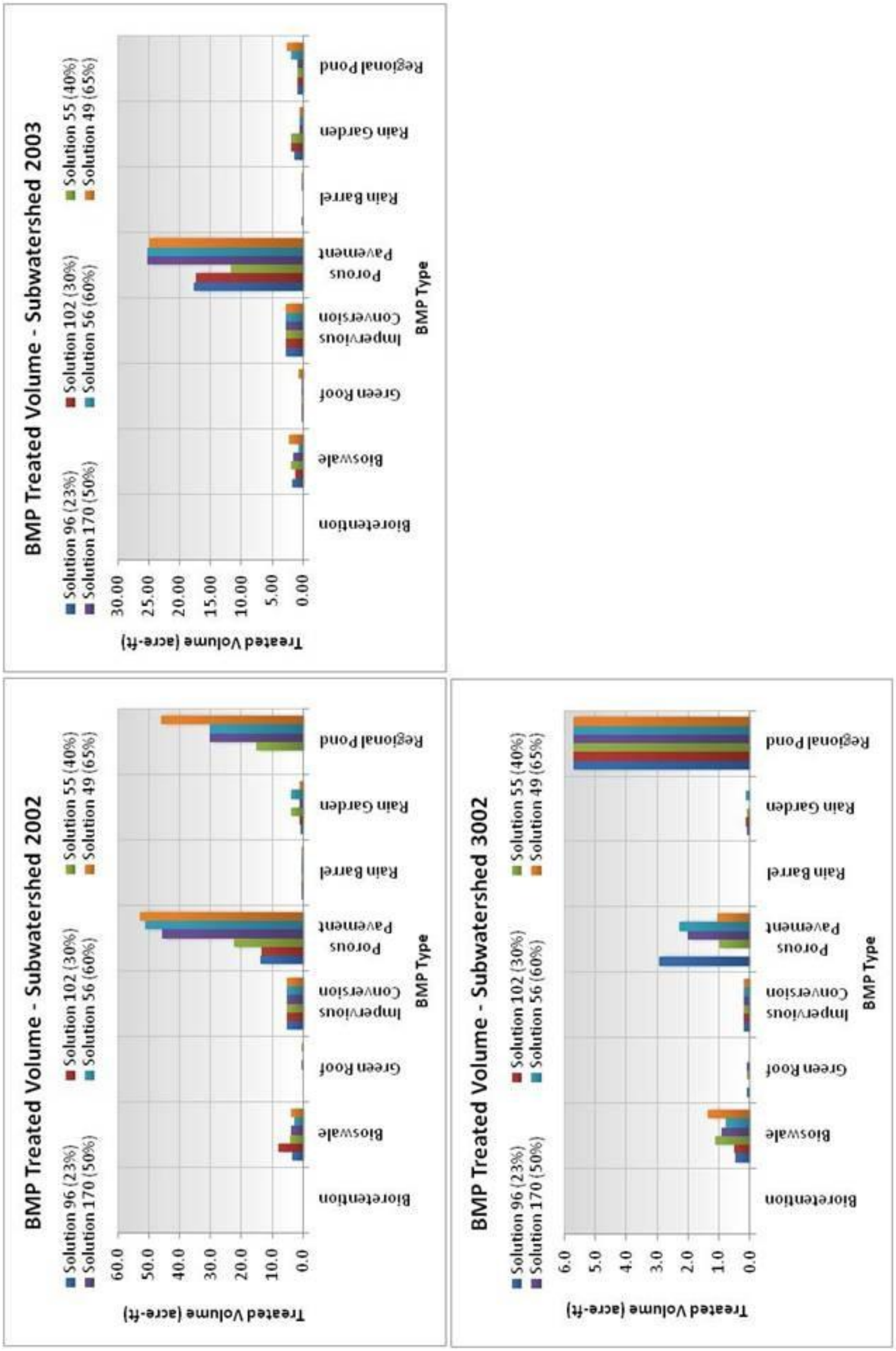


Figure 8-8. BMP volume reduction for subwatersheds 2002, 2003, and 3002.

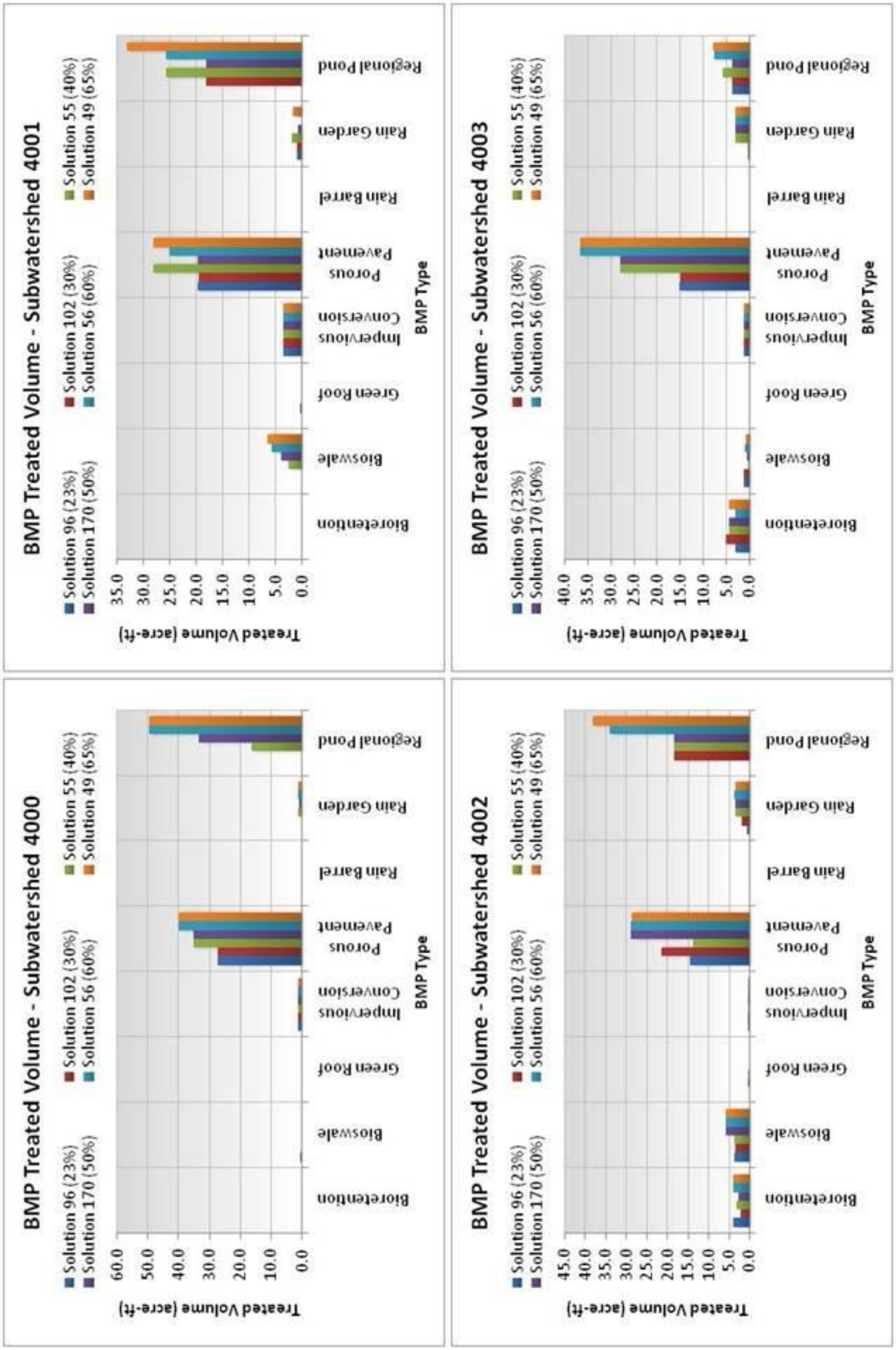


Figure 8-9. BMP volume reduction for subwatersheds 4000-4003.

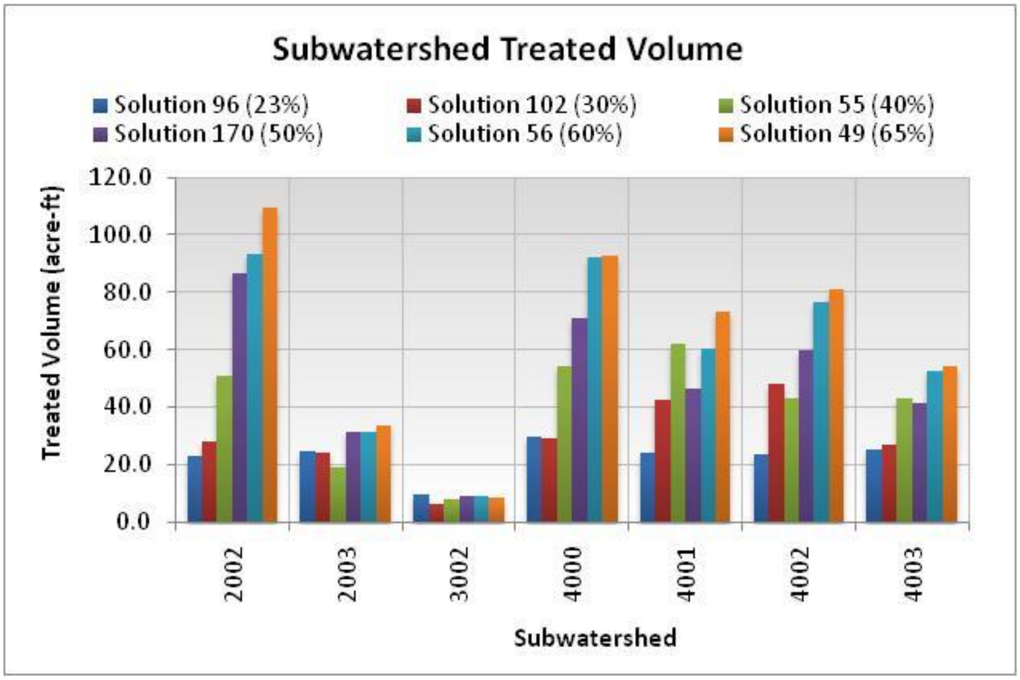


Figure 8-10. Subwatershed BMP network volume reduction totals.

Table 8-5. Subwatershed BMP network volume reduction totals

Sub-watershed	Volume Treated (acre-feet)					
	Solution 96 (23%)	Solution 102 (30%)	Solution 55 (40%)	Solution 170 (50%)	Solution 56 (60%)	Solution 49 (65%)
2002	23.1	27.8	50.9	86.7	93.4	109.3
2003	24.6	24.4	19.2	31.2	31.4	33.6
3002	9.5	6.5	8.2	8.9	9.1	8.3
4000	29.5	28.9	54.2	71.2	92.4	92.5
4001	24.2	42.5	61.8	46.4	60.2	73.1
4002	23.6	48.1	43.2	59.6	76.5	80.8
4003	25.3	27.2	43.0	41.2	52.8	54.2
Total	**159.7**	**205.5**	**280.5**	**345.2**	**415.8**	**451.9**

Blue – red denotes low – high

As discussed in the Section 8.1, the volume reduction attributed to groundwater recharge and evapotranspiration for each BMP is consistent across solutions and is a function of the BMP designs, which are outlined in Table 8-2. Green roofs are only capable of volume reduction through evapotranspiration, while bioretention, bioswales, porous pavement, rain garden and regional ponds act primarily to infiltrate runoff. Impervious areas converted to pervious land show a relatively even split between evapotranspiration and infiltration, primarily as a result of the slow infiltration rates of the native soils.

8.2.3 Treatment Depths

To investigate the efficiency of treatment in each pilot area subwatershed, the treatment depth of each was assessed for all solutions. Treatment depth was calculated as the treated volume divided by the contributing drainage area. If the BMPs in a subwatershed were 100 percent efficient the BMP network would, in effect, treat all rainfall that was captured by the contributing drainage area. The average annual rainfall for the modeled time period (1992–1994) is 41.8 inches. The closer the treatment depth to this value, the more efficient the BMP network within a subwatershed was at treating captured rainfall. Figure 8-11 through Figure 8-16 present the treated volume and depth of the BMP network of each subwatershed for the six selected solutions.

On the basis of treatment depths the most consistently efficient subwatershed is number 4002. This subwatershed has the largest BMP opportunity for porous pavement (3.59 acres), which was identified as one of the more efficient BMPs. Overall, efficiency begins to drop when volume reductions exceed 30 percent (Solution 102), as was also observed in the pilot area wide assessment of treatment depths. As described earlier, this indicates that as the drainage areas of the BMPs expand they are less able to treat the volumes generated by the largest storms.

8.2.4 Summary of Subwatershed Results

Below is a summary of observations from the subwatershed analysis:

- Similar to what was observed throughout the entire pilot area, as the level of treatment increases, all BMP utilization increases. The trend is less well defined, and utilization shows more variability across solutions. In general, however, the utilization of a BMP within a subwatershed is more likely to show an increasing trend the larger the BMP opportunity, which is usually the case for porous pavement and regional ponds. There was no consistent trend in total BMP utilization by subwatershed, however.
- Porous pavement and regional ponds generally show the largest volume reductions for all scenarios in all subwatersheds. The exception is subwatersheds 2003 and 4003 where opportunities for regional ponds are very small. Bioretention, bioswale, and rain garden BMPs show comparable volume reduction across all scenarios. Green roofs generally show the second smallest volume reductions, followed by rain barrels, which provide the smallest volume reductions consistently across all subwatersheds and solutions.
- Subwatershed 2002 shows the greatest volume reductions for the 50, 60, and 65 percent flow reduction scenarios and subwatersheds 4000, 4002, and 4001 showed the greatest volume reductions for the 23, 30, and 40 percent flow reduction scenarios, respectively. Overall volume reduction by subwatershed is positively correlated with BMP opportunity and BMP utilization.
- BMP treatment depths ranged from approximately 10 inches in subwatershed 2002 for the 65 percent reduction scenario to approximately 20 inches in subwatershed 4002 for the 30 percent reduction scenario. At the subwatershed scale, this indicates that the maximum percent capture of annual average rainfall (41.8 inches) by the modeled BMP networks is a little under 50 percent.

On the basis of treatment depths the most consistently efficient subwatershed is number 4002. Overall, efficiency begins to drop when volume reductions exceed 30 percent (Solutions 102), as was also observed in the pilot area wide assessment of treatment depths.

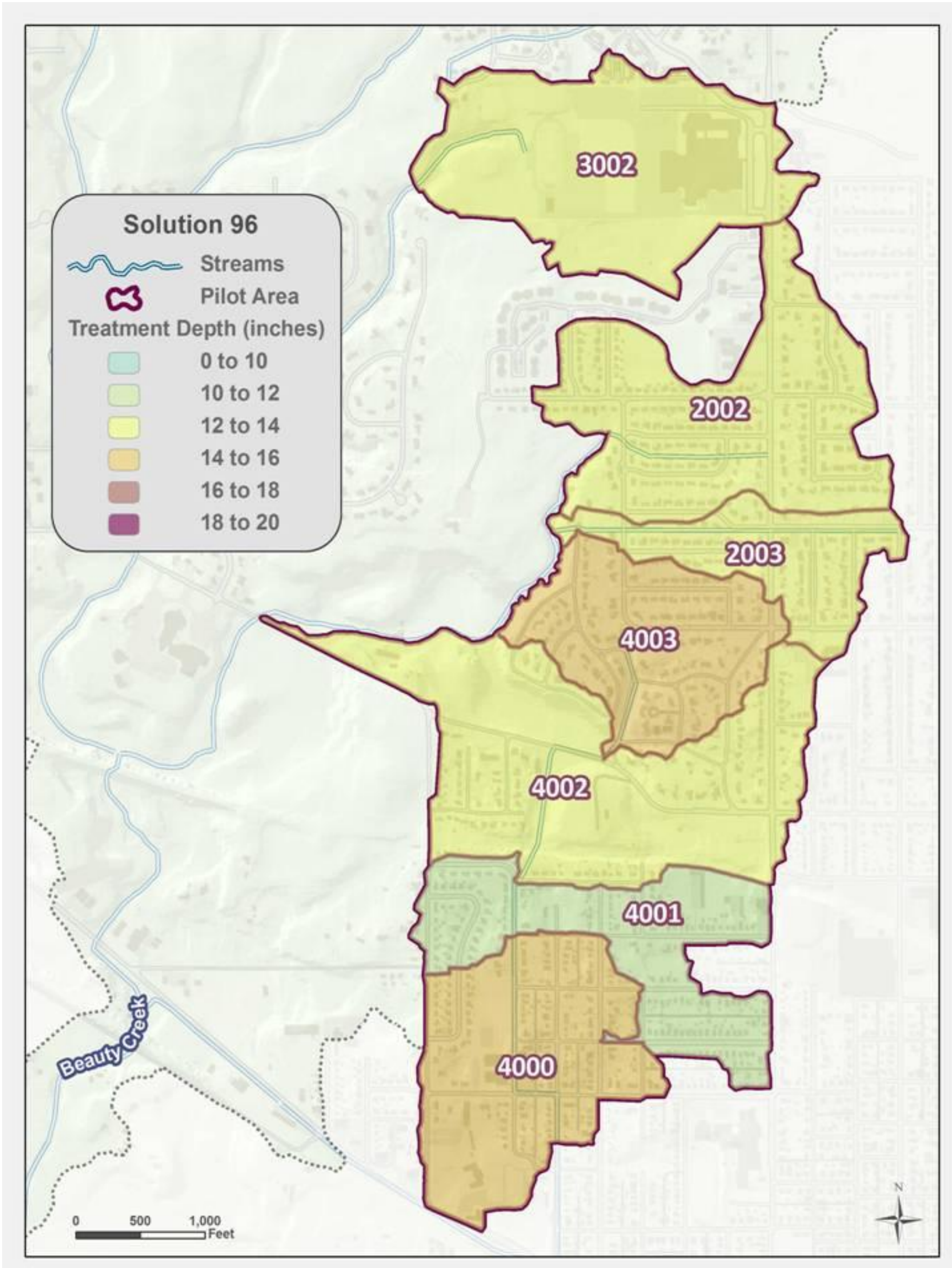


Figure 8-11. Subwatershed BMP network treatment depths for Solution 96.

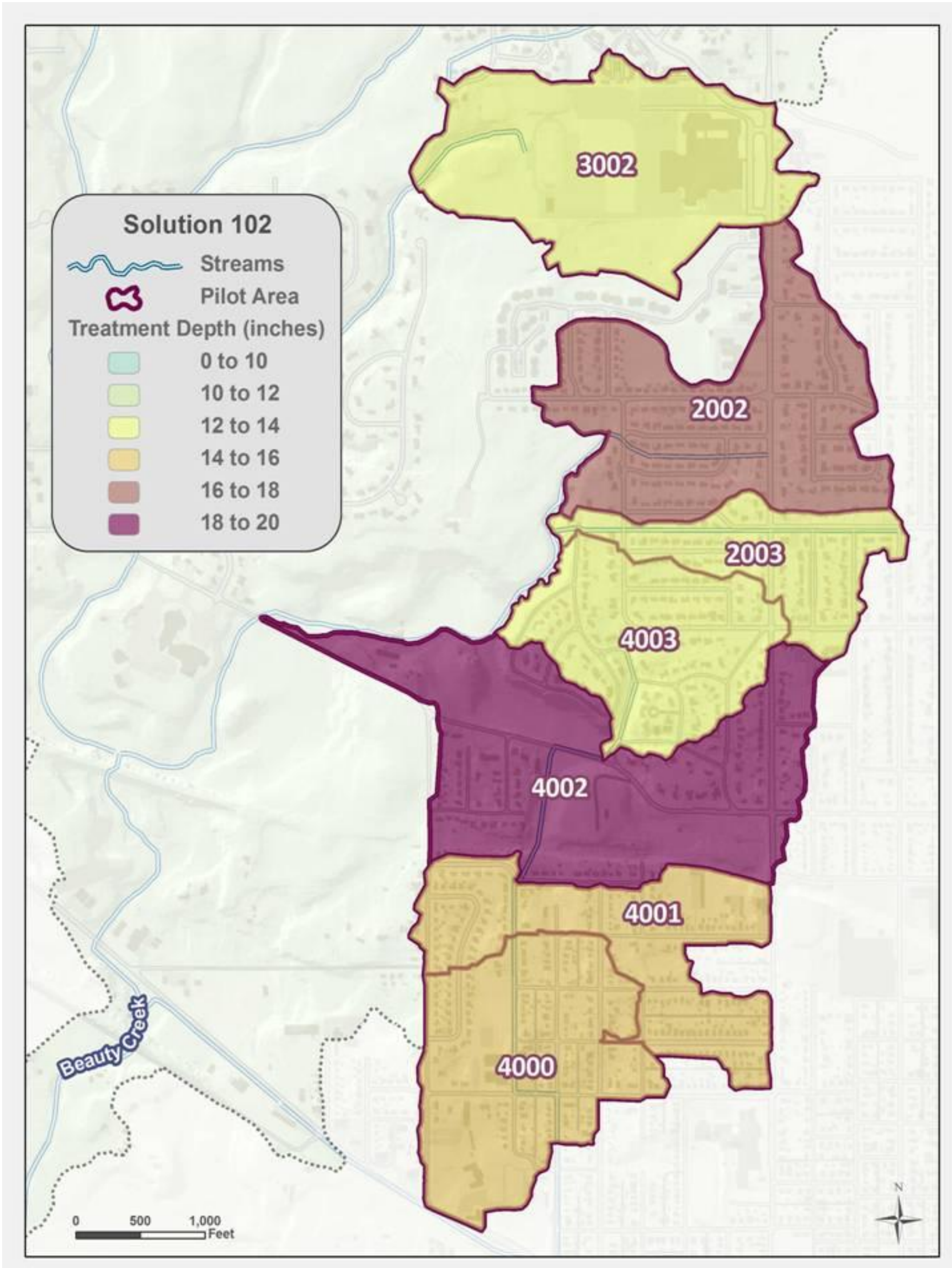


Figure 8-12. Subwatershed BMP network treatment depths for Solution 102.

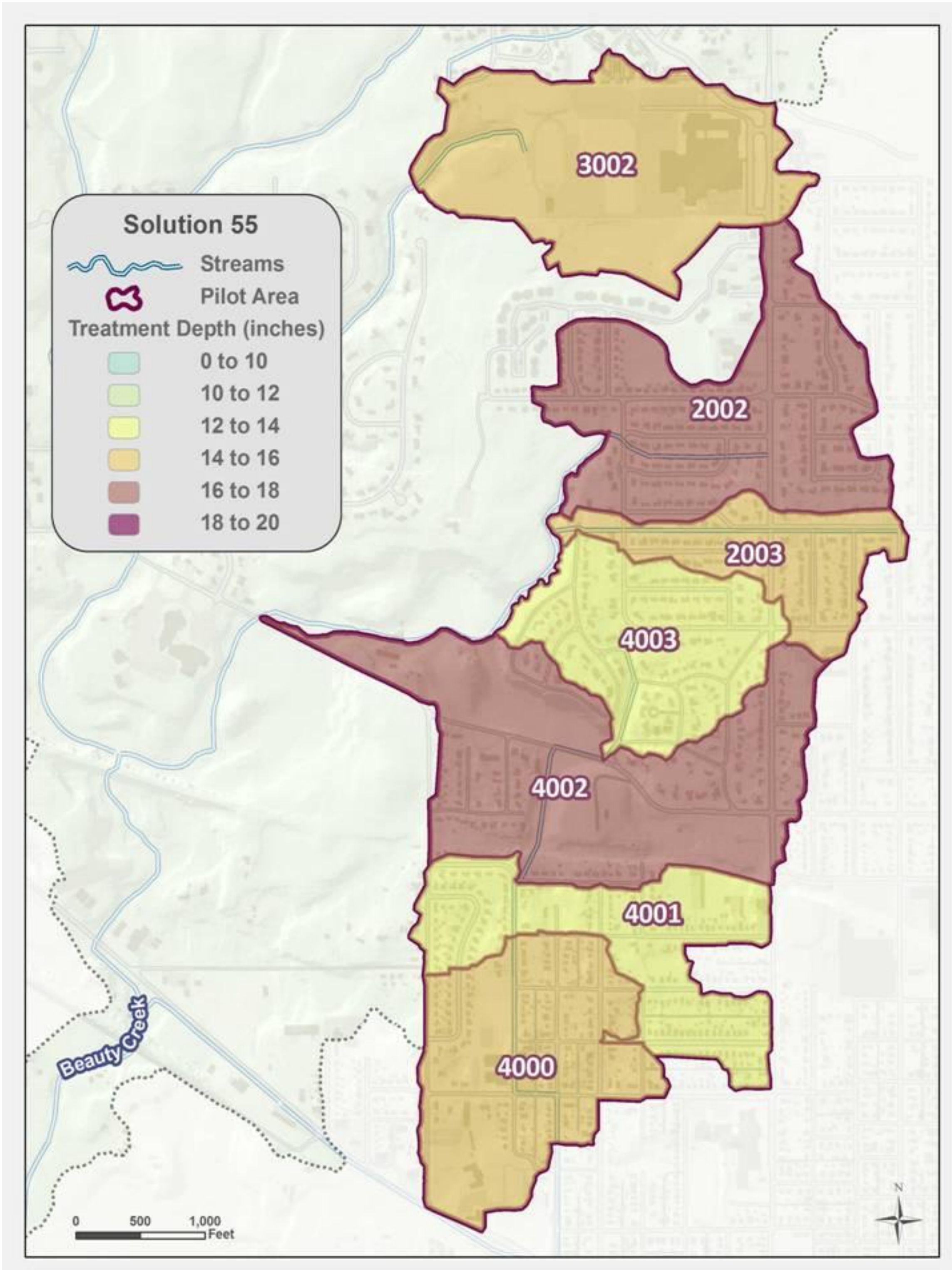


Figure 8-13. Subwatershed BMP network treatment depths for Solution 55.

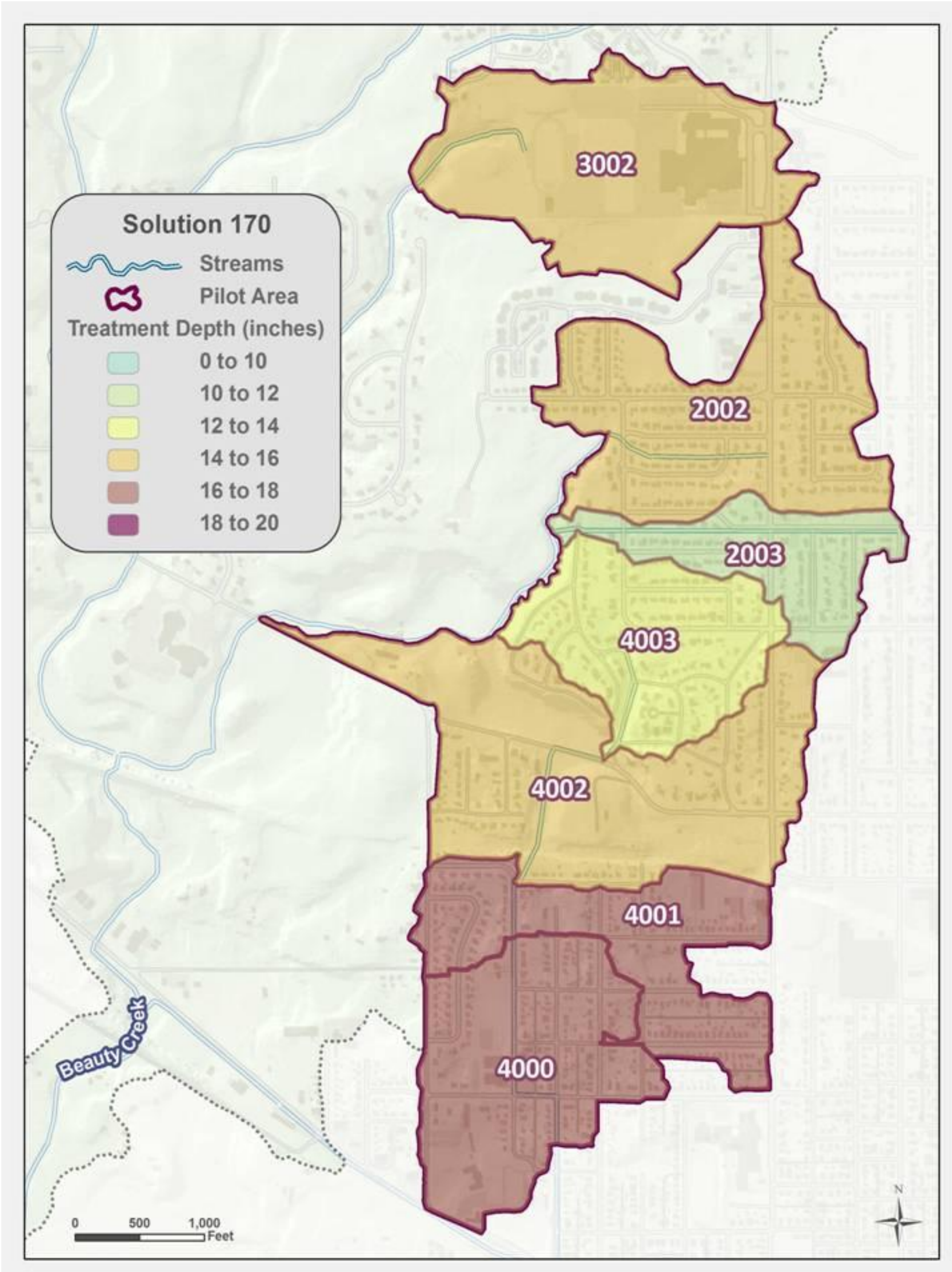


Figure 8-14. Subwatershed BMP network treatment depths for Solution 170.

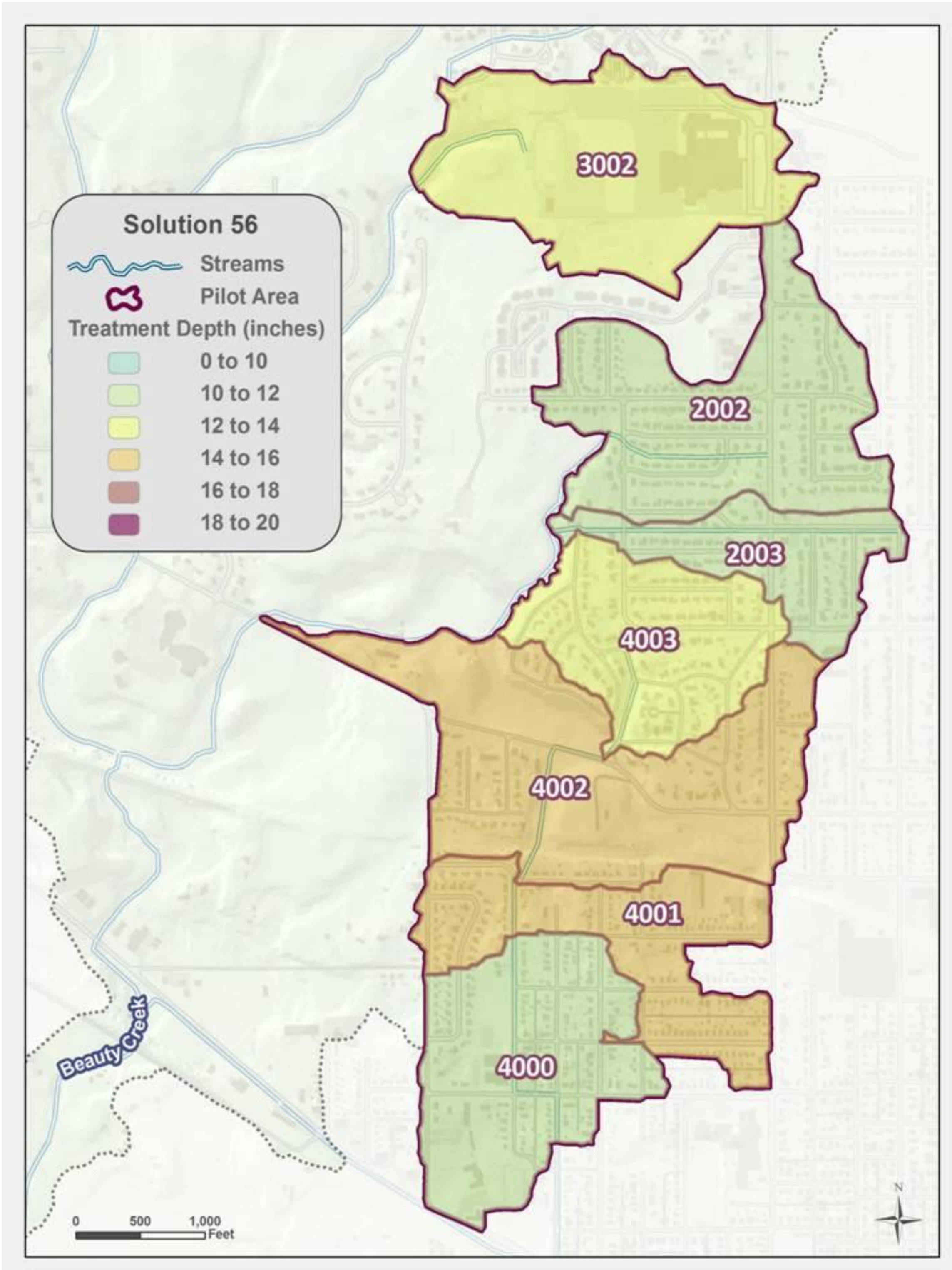


Figure 8-15. Subwatershed BMP network treatment depths for Solution 56.

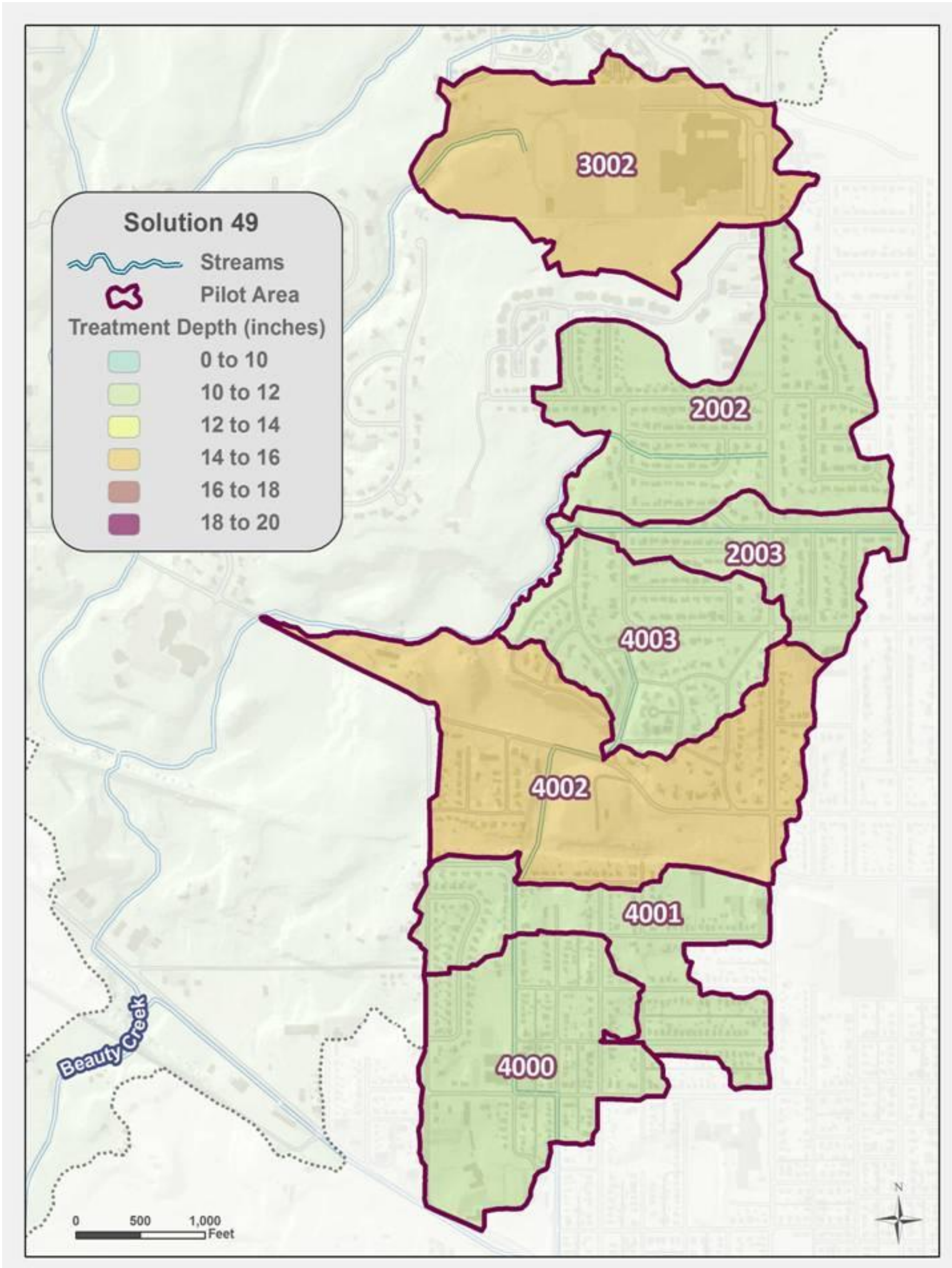


Figure 8-16. Subwatershed BMP network treatment depths for Solution 49.

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